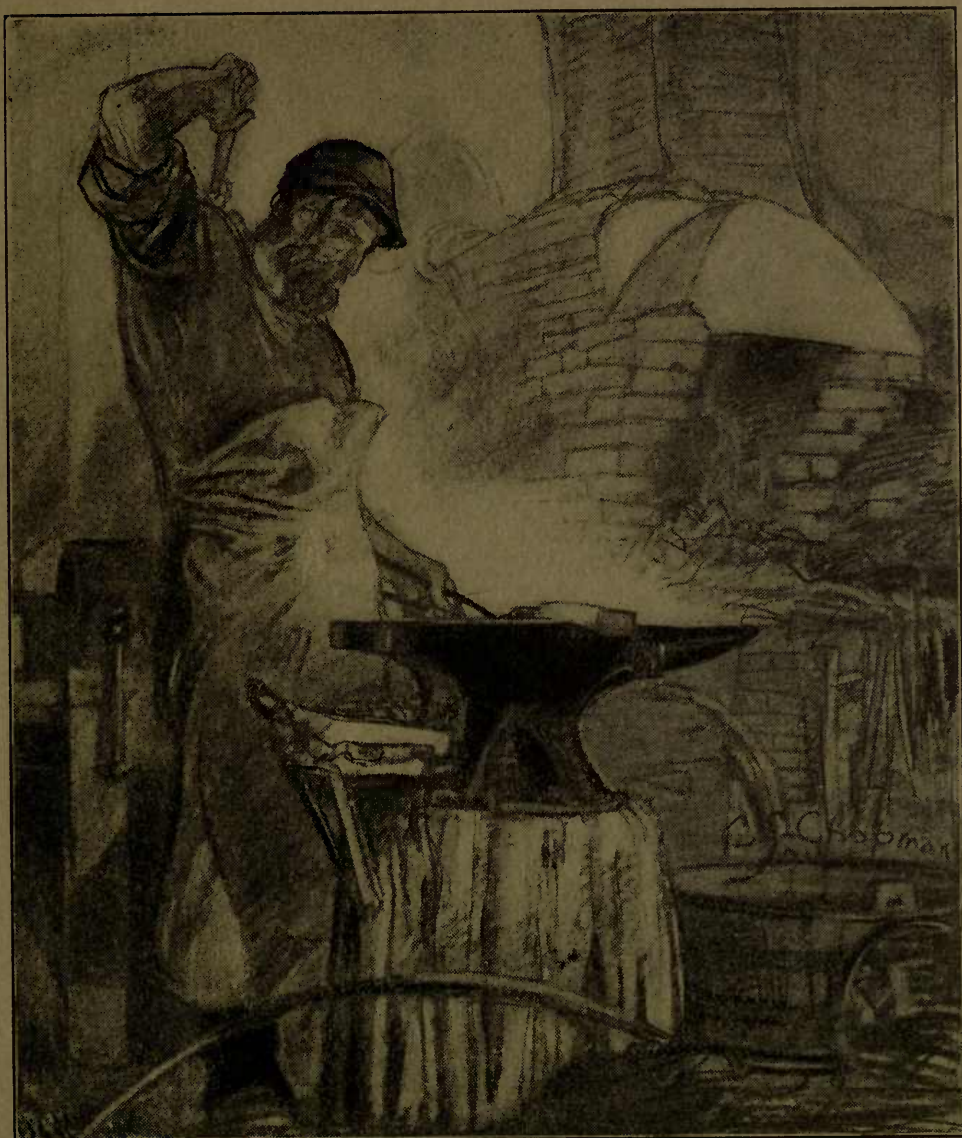
ELEMENTS
OF
INDUSTRIAL HEATING



September, 1922 No.

DEMAND for the educational papers relating to principles and practice of industrial heating that we have issued, has led to their revision and publication in this convenient form, to better meet requirements for a supplementary textbook for shop training classes, vocational schools, colleges, etc., as well as for the man in the shop and others interested in the subject.

THE purpose of this booklet is to draw attention to essential factors governing the quality and cost of products subjected to the action of heat in the process of manufacture, and the selection and use of equipment, fuel or electricity necessary to produce better results at lower cost.

The influence of heat upon the quality and cost of practically all manufactured products, and the comparatively inefficient methods in general use, indicate the necessity of developing a broader view of the industrial heating problem.

The demand for better and cheaper products can only be met with better methods of heating and handling, better equipment, and above all, men better qualified to understand and properly apply in practice the simple principles of one of the oldest and most important, though indifferently practiced, industrial arts.

The views outlined are the result of years of practical experience with a great variety of heating operations and direct contact with actual manufacturing conditions. This has taught the necessity for a better understanding of the underlying principles and purposes of industrial heating operations, the results of which should be measured in terms of quality and cost of finished product—not merely cost of fuel or labor, mere tonnage of output, nor indication of temperature control. Such factors are too generally accepted as determinative, although they bear about the same relation to the result sought in industrial heating as in illumination or transportation.

CONTENTS

Variety of Industrial Heating Processes

THE variety of industrial heating processes is rarely realized except by those directly concerned with the development of improved methods of heating and handling to meet the need for better and cheaper products in the metallurgical, chemical, ceramic and other industries.

The use of heat in practically every branch of industry has naturally resulted in the development of different methods of generating heat from fuel or electricity; many different methods for the application and utilization of heat in the product, and a great variety in furnace design and equipment for handling the material to be heated or cooled.

The ever-increasing demand for better quality and lower cost of product and improvement of working conditions for the operatives directs attention to the ever-important question as to the manner of applying heat to the product, which is so directly related to quality, and the influence of methods of heating and handling and design and layout of furnace equipment upon the cost of production.

The fundamental principles affecting the application of heat are fixed, but there is an untold variety in method of applying these principles in different processes to meet the great variety of manufacturing requirements and plant conditions.

In certain lines of manufacture, experience has determined the method of heat application and the physical or mechanical requirements of the process, which in a large measure influence the type, size and general arrangement of furnace equipment and the form of fuel or electricity to employ for generating heat.

The latitude for improvement is frequently confined to refinement in design of furnace and auxiliary equipment and in methods of generating or utilizing heat and handling material to be heated and cooled, etc. Often there is apparently little room for material improvement without a radical change in the nature of the manufacturing process. Frequently, the heat-treatment process is conducted with methods and equipment which are passable under certain conditions but are not really suited to the operation in hand, making it exceedingly difficult to materially improve the quality or decrease the cost of production. Such conditions generally warrant the policy of ignoring precedent, usually the result of circumstance, and starting afresh from the fundamentals of the problem.

The "human element" is the ultimate controlling factor, and bears about the same relation to the heat-treated products of the shop that the cook bears to the heat-treated products of the kitchen. The common and wasteful practice of delegating to unskilled men the control of important heat-treatment processes, which so frequently affect subsequent operations and value of the finished product, must be corrected in the practice of the future.

The need of the moment is for improved methods of heating and handling and competent operatives or supervisors who understand the principles affecting the generation, application and transfer of heat, and who can properly employ furnaces, fuel or electricity, pyrometers, etc., as tools for the conduct of the ever-important work of "heat application."

The variety of methods of heating and handling, and design and layout of furnaces that may be used in the various industries, is generally unknown to those not familiar with the wide range of processes, manufacturing requirements and plant conditions, and the possibility of effecting improvement in one line of manufacture through experience gained by practice in others.

To the average man, a furnace means that piece of necessary equipment in the cellar of his house which is more or less a nuisance and expense for six to nine months of the year.

The furnace horizon of the **blacksmith** extends very little beyond the smith fire which serves for general forging or heat-treating of the small pieces of metal to which it is adapted.

The **drop forger** sees little more than a comparatively small uncomfortable furnace with an uncovered opening in front, through which the material to be heated is introduced and withdrawn.

The **smith** accustomed to heavy forge work and steam hammers or hydraulic presses is more at home with the single-door or multi-door forge furnace, and occasionally with some type of large annealing or heat-treating furnace.

The **foundryman** engaged in the production of iron castings is concerned primarily with the cupola and core oven, though he may be familiar with air furnaces for melting, and annealing ovens if malleable iron castings also are produced.

The **brass founder** is interested in little beyond his crucible pit fires and core ovens, though in some instances he may be familiar with the tilting type of crucible or reverberatory melting furnaces, or with electric melting furnaces.

The **rolling mill man** producing brass or copper products is familiar with coal or coke pit fires for melting brass in crucibles, or perhaps with the tilting type of electric furnaces in which the heat may be released through induction, or through some form of arc or resistance. He is also familiar with large annealing muffles; and, if engaged in the manufacture of metal specialties, with other types of furnaces for annealing, brazing and other operations. If he manufactures brass or copper wire or tubes, he will undoubtedly know various types and sizes of billet heating furnaces, and even scaling or cake heating furnaces if producing sheets or plates.

Those engaged in the production of **copper** are primarily interested in smelting furnaces for reducing the ore or in large reverberatory furnaces for refining the metal.

Those concerned with the manufacture of **steel** are familiar with furnaces of quite different designs, there being a wide variety to meet the requirements for steel sheets, wire, rods, pipes, etc., starting with the blast furnace and followed by the open hearth, converter, or electric melting furnaces, the soaking pit, billet heater and other units to meet the heating, forging, welding, and annealing requirements.

Even **steel mill men** producing structural products are frequently unfamiliar with the extremely wide variety of furnaces for heating, forging, and heat-treating required in the fabrication of alloy steels into manufactured products, ranging from heavy ordnance to the smallest needles.

The **production manager** in the large automobile or similar plant fabricating large quantities of different kinds of metal in assorted sizes has a broad range of vision in the industrial heating field, which includes many of the furnaces previously referred to and various types of other furnaces more or less special in nature to suit production requirements for normalizing, hardening, carbonizing, annealing, and miscellaneous heat-treating operations.

The **chemical engineer** is confronted with some interesting heating problems, which require a wide range of furnaces adapted to the special nature of his processes and the manufacturing requirements and plant conditions governing his practice.

The outline of principles and illustrations of their practical application in different lines of industry, which follow, have been compiled in the belief that the information will be of benefit to those interested in industrial heating processes, by indicating the opportunities for improving the quality and decreasing the cost of production by better methods of heating and handling, which frequently result from proper selection and use of "FURNACE AND FUEL TO SUIT CONDITIONS."

Factors Governing Quality and Cost of Heat-Treated Products

THE importance of the application and utilization of heat in manufacturing processes should lead to a thorough consideration of the factors that govern the production of heat-treated products and the selection and use of furnaces and fuels as a means to that end.

Heat in one way or another affects the quality and cost of practically every manufactured product. Its influence is far-reaching, particularly in the manufacture of metal products, yet it is doubtful if there is another manufacturing process as important as industrial heating so generally neglected and misunderstood.

The selection of methods, equipment and fuel is frequently made difficult by widely divergent recommendations, based on opinion or prompted by commercial interest, which cloud the real problem.

Many essential factors must be considered in the problem as a whole, including intangible values which cannot be definitely measured on account of evolution in the art and the ever-changing economic, industrial and manufacturing conditions.

Essentials may be overlooked in abstract consideration of related details, such as fuel values, methods of releasing heat, temperature control, furnaces, burners, pyrometers, control devices, etc.

The problem boils down to selecting the combination of raw materials, methods, production equipment and facilities and personnel, which, when properly adapted to individual manufacturing requirements and plant conditions, will most nearly accomplish the result sought, i. e., the production of quality product at minimum cost. Every detail, technical or otherwise, is but a means to this end.

It is as much a waste for the manufacturer to use the wrong form of heat energy (fuel or electricity), regardless of its cost on the basis of "heat unit value," as it is to waste the right form of heat energy or raw material in furnaces improperly designed, constructed or operated, regardless of heat balance.

Selection may be simplified by consideration of the factors outlined by the chart on page 5, which govern every industrial heating operation, whether it be baking a loaf of bread or melting, forging, or heat-treating tons of steel.

Quality and cost of finished product are the basic factors. There are many contributing factors, including the human element, any one of which may influence the ultimate result.

Consideration of factors affecting quality must include the manner of cooling as well as heating, and the effect of atmosphere. Uniform heating **prepares** material for uniform heat-treatment; the adjustment of the structure and final set in cooling actually **determine** the uniformity of the heat-treatment.

Uniformity of heating and cooling is governed by factors many of which are not generally considered. Control of furnace chamber temperature is but one of the factors influencing uniformity of heated product. Of primary importance are uniform application of the heating or cooling medium to the surface of each piece of the charge, the rate of heating or cooling, degree of saturation and the effect of atmosphere inside and outside the furnace.

Temperature must be considered with the element of time and the surface exposure of each piece to the heating and cooling mediums. The relation of surface to mass is the basic factor determining time of exposure, other conditions such as conductivity of material, rate of heating or cooling, etc., being equal. The shape of the individual pieces, affecting the relation of surface and mass, or a mere change in shape without a change in weight or composition, may dictate changes in the method or rate of heating, cooling or handling. With highly figured dies or irregularly shaped forgings or castings, it is desirable to heat slowly to prevent overheating the thin sections or sharp corners, which, by reason of large surface in proportion to mass, are heated and cooled more rapidly.

The all-important work of properly applying heat to the product is frequently neglected by consideration of related conditions, such as "temperature control," "fuel values," methods of releasing heat through combustion or electricity, or methods of indicating or controlling temperature.

The cost of heat energy in the form of fuel or electricity is frequently accepted as a standard by which to measure heating cost, but it **is of little value without consideration of other factors determining quality and ultimate cost of product.**

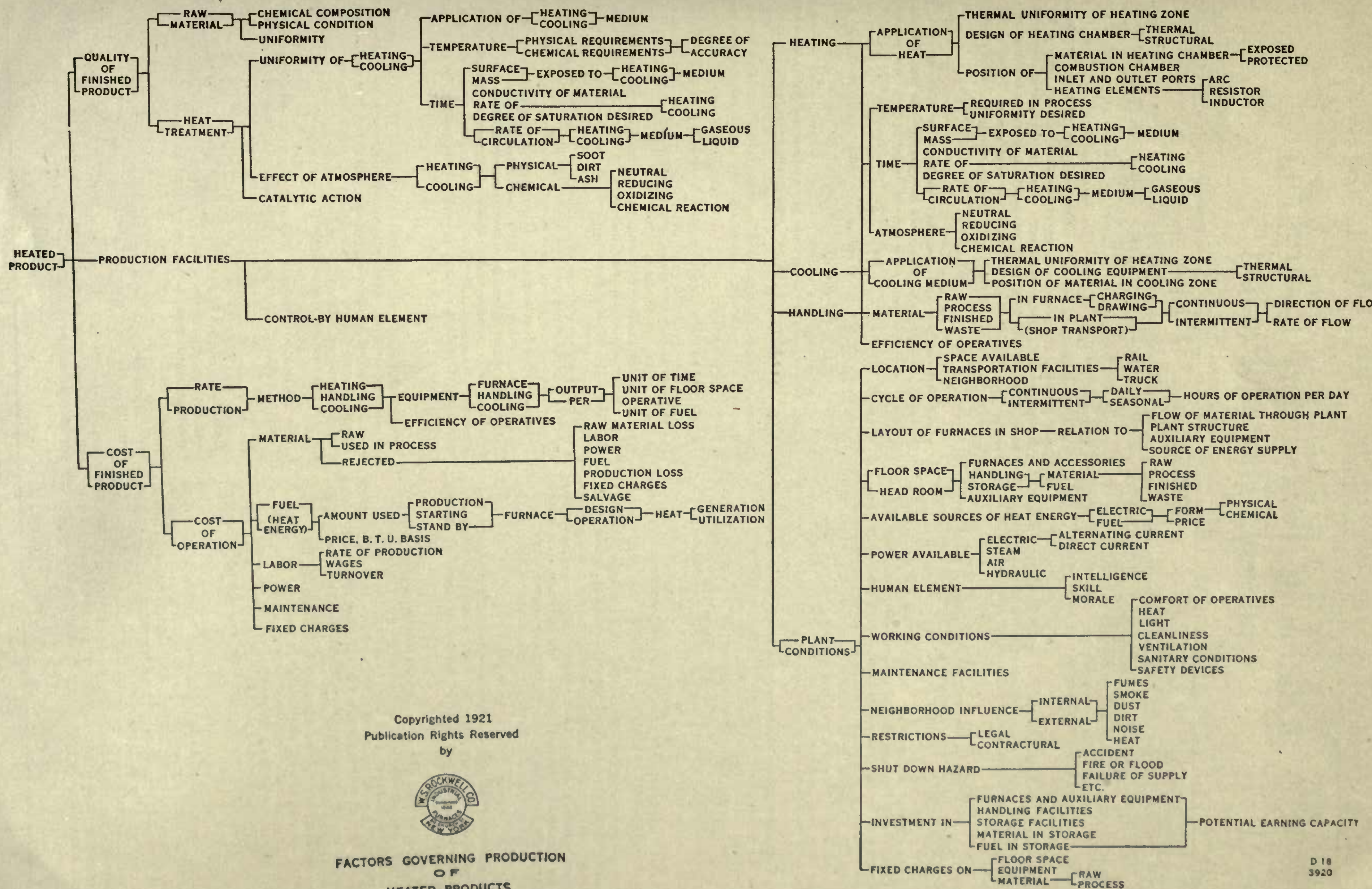
Fuel cost, which includes quantity consumed as well as price, **is but one item in the final cost of heating,** just as it is but one item in the final cost of illumination or transportation. In all cases, the design, operation and suitability of the appliance, whether it be a lamp, boiler, engine, motor truck or furnace, must be considered in relation to the quality and cost of the ultimate result. Fuel consumption records bear about the same relation to manufacturing or transportation costs that pyrometer records bear to quality of product.

Industrial heating results cannot be measured, as in power, illumination or transportation, by definite standards, such as the horse power hour, kilowatt hour, candle power hour, ton mile, etc., because of the many variable factors influencing the quality and cost of finished product.

Cost per unit of given quality—not cost of fuel, of labor, of tonnage output, nor indication of temperature control—is the determinative test of an industrial heating operation.

The human element cannot be eliminated by devices which govern supply of heat energy, except in rare cases where the manufacturing routine does not vary in essential detail. Variations in size, shape, weight, quantity, rate of flow, time of exposure, composition of material, or in the heating or cooling process, require skill and judgment on the part of the operative. Recognition of the difference between control of temperature and means of releasing heat on the one hand, and control of other essential factors related to finished product on the other hand, should cause appreciation of the importance of the human element.

Low first cost of material, or fuel, or equipment, or labor does not assure low cost of quality product. **Improvement in quality and decrease in cost, or both, will result only from a proper co-ordination of all factors.**



FACTORS GOVERNING PRODUCTION OF HEATED PRODUCTS

Fig. 1

Relation of Temperature Control to Uniformly Heated Product

INDICATION of temperature control is frequently accepted as evidence of a thermal condition suited to the production of a uniformly heated product, regardless of the fact that indication of uniform furnace temperature does not of itself establish the uniformity of a heating or cooling process.

Uniform temperature is necessary to produce uniformly heated product, but **heating a chamber uniformly and uniformly heating a charge within that chamber are two distinct matters.**

Indication of temperature control is misleading without consideration of other factors affecting the uniform heating or cooling of the product, as outlined by the chart on page 7.

Of primary importance are the uniformity of heat application to the surface of the individual piece, the time of exposure and the rate of heating. Variation in product may be caused by differences in furnace design, in placing of charge in the chamber, in the time of exposure and in rate of heating or rate of charging and discharging, resulting in difference in the application of heat to the charge, without any indication of chamber temperature variation.

The ideal condition for the production of properly heated product is nearest attained when the heating and cooling mediums are uniformly applied to the entire surface of each piece or section in the same manner, at the same temperature, at the same rate, for the same time, in the same atmosphere, in equipment properly adapted to the nature of the process, production requirements and plant conditions.

The relation of indicated chamber temperature to heated product is illustrated by the diagram on page 7.

The pyrometer chart is the record of a furnace in actual operation. Although it might be assumed that a charge would be uniformly heated in any furnace recording such a chart, there is a marked variation in the heating of the charge in many of the furnaces (1 to 11) **even though the indicated chamber temperature and time of heating are the same.** The approximate locations of the incompletely heated zones are shown by the shaded sections.

The electric furnaces (5, 6, 7) are not exceptions to the rule, for while they are alike in manner of generating and controlling the heat, they differ in manner of applying it and in method of handling the charge.

The product will likewise vary in uniformity in each of these furnaces, depending on distribution of the charge—mass and surface exposed to heat—although there may be no variation of indicated chamber temperature or time of heating. Diagrams "A" to "O" illustrate the variation from uniformity resulting from different methods of distributing the same charge.

The rate of heat input must be intelligently considered whenever there is a material variation in the mass or surface of the pieces. Such variations may warrant changes in type or design of furnace in order to control the rate of heating, time of exposure, and placing of the charge in the chamber, independently of the manner in which the heat itself may be generated, controlled or indicated.

With the method of loading illustrated by diagram 12, it is apparent that if the pieces of the charge were handled individually, the one first placed in the chamber would be the last withdrawn, and the piece last charged the first withdrawn. If all the pieces of the charge were withdrawn when the one first introduced was fully heated, and if this one had been introduced at approximate working chamber temperature, **there would be a difference in time of exposure and degree of saturation of all the pieces.** If the pieces were placed close to or on top of one another, the condition would be still more unfavorable. In such a furnace, regardless of the uniformity of temperature or method of generating or applying heat, a charge will not be heated uniformly unless it is introduced and withdrawn as a unit, or unless the furnace and charge are slowly heated together.

A cold charge placed in a hot furnace will absorb heat rapidly, causing a drop in chamber temperature, whether it be indicated by the pyrometer or not. The temperature drop and time of recovery will be greater in a light furnace than in a heavy furnace of the same type and chamber area. The greater heat storage in the heavier furnace is of advantage in minimizing such drop and time of recovery, in addition to effecting economy in operation.

The temperature will also vary with the regularity of input and outgo of material and heat; and with the relation between the temperature, mass and surface exposure of material in the chamber, and the temperature, mass and surface exposure of material which follows. The actual temperature fluctuation will decrease with the subdivision of the charge as the torque of a gasoline engine or diagram of pump flow becomes more uniform with an increase in the number of cylinders.

Determination of such factors as placing of charge in the chamber, methods of handling, and suitable arrangement of furnace equipment, etc., must include consideration of the **manner of applying heat to the charge,** i. e., whether it be transferred by radiation, convection or forced circulation of chamber atmosphere.

While in both fuel-fired and electrically heated furnaces a great deal of the heat is transferred by radiation, a considerable amount is transferred by the circulation of the chamber atmosphere.

Heating by radiation alone is frequently undesirable in fuel-fired furnaces of the muffle type or in electric furnaces in which there is no forced circulation of the heating chamber atmosphere, because of the difficulty of **properly transferring heat to the entire surface of the charge or individual unit,** and the consequent possible lack of uniformity.

Much of the heating that is supposed to be conducted solely by radiation is actually performed by convection currents brought about by a temperature differential, which naturally creates motion and prohibits existence of the so-called "quiescent atmosphere." The rate of circulation of such convection currents is influenced by the temperature differential and the relative mass and exposed surfaces of the receiving and emissive bodies.

Frequently, as in the operation of electrically heated japanning ovens or fuel-fired furnaces of the muffle type, in the chamber of which there is but a slight temperature differential, it is necessary to provide for forced circulation of the chamber atmosphere in order to permit of efficient heat transfer, which would be unnecessary if the temperature differential were greater.

The continuous furnace (13) may be employed in a variety of designs and methods of heat generation, with improved quality of product resulting from uniformity of heat application, and time and rate of exposure, and with lowered operating cost, resulting from the efficient method of handling the product and directly utilizing the heat. The field of usefulness of the continuous furnace, however, is determined by the size and shape of the pieces to be heated, as well as by the quantity and regularity of their flow.

Uniform heating is a relative term. Absolute uniformity is rarely, if ever, attained.

Practical uniformity of heated product is secured only by the proper co-ordination and application of all factors essential to the selection and operation of industrial heating equipment.

RELATION OF TEMPERATURE INDICATION TO HEATED PRODUCT

THE INFLUENCE OF FURNACE DESIGN AND MANNER OF LOADING
UPON UNIFORMITY OF MATERIAL HEATED IN FURNACES OF DIFFERENT TYPES
EACH CAPABLE OF MAINTAINING UNIFORM TEMPERATURE INDICATION AS SHOWN

D-26
2821

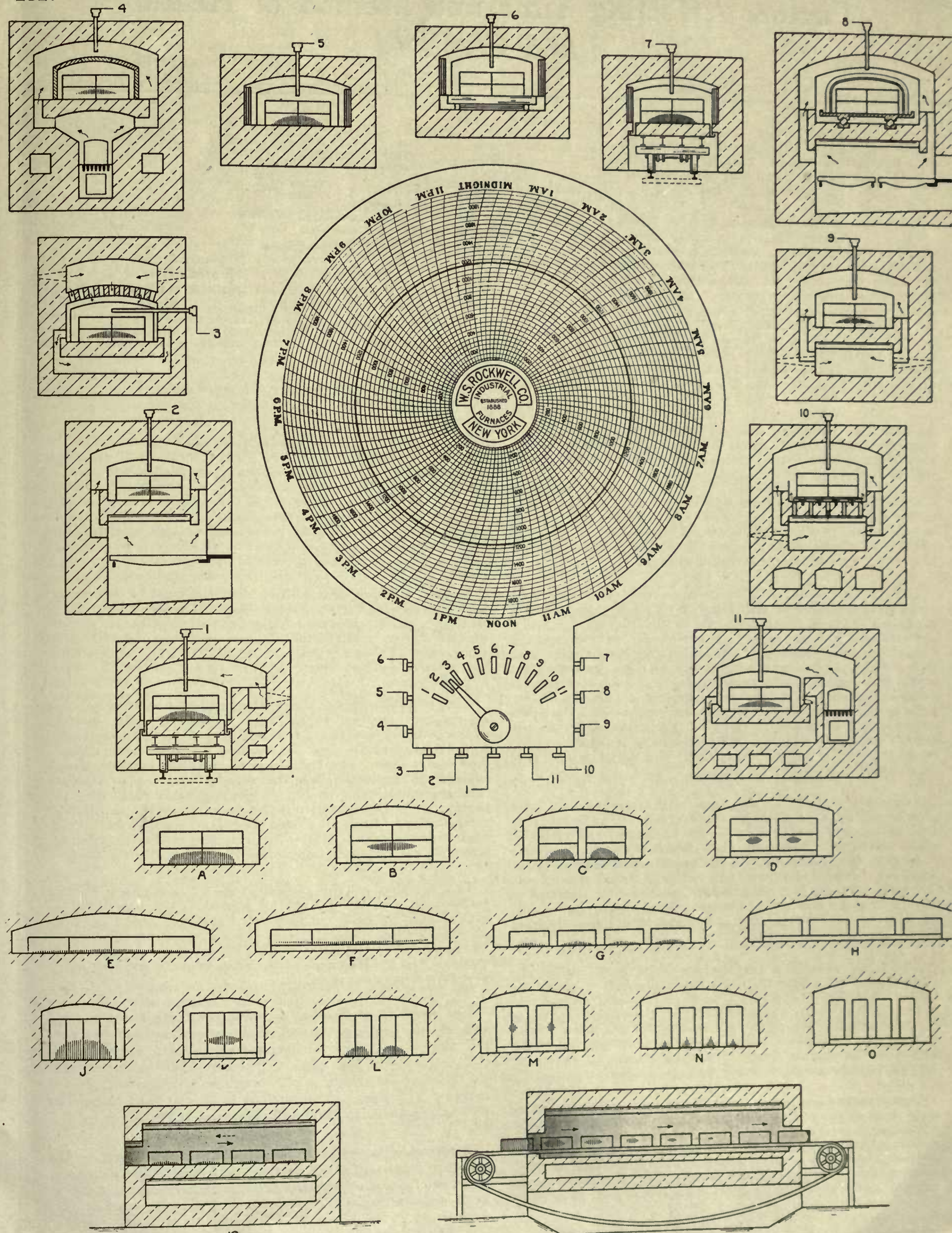


Fig.

Factors Affecting Time and Method of Heating and Cooling

TIME — the period required for heating or cooling—is a vital factor in all processes involving the application of heat.

The influence of the "time factor" is not generally appreciated in practice, due no doubt to a misunderstanding of its importance and the many variables that affect it. Unwarranted emphasis on "temperature control" as the essential element in heating or cooling operations, and "output," "fuel consumption," etc., as the determination of cost, frequently leads to **neglect of the influence of the time and manner of exposure and the rate of heating or cooling upon quality and cost of the finished product.**

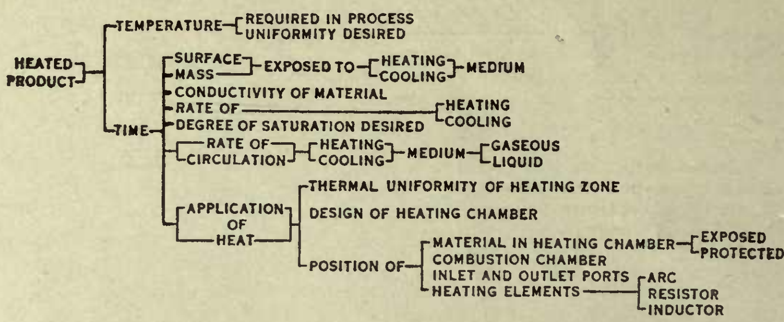


Fig. 3. Factors Determining Uniformity of Heating and Cooling

Control of time and rate of heating or cooling is just as essential as control of temperature. Time and temperature are so inseparably linked that it would be well to associate the two as one controlling factor—"time-temperature." The use of such a term may tend to discourage the usual abstract consideration of temperature without regard to the time necessary to attain a given temperature; and to encourage the thought that there are a number of factors in addition to control of temperature that influence the uniformity with which a given piece is heated or cooled.

The "time factor" is just as important in heating or cooling operations in the shop as it is in the cooking processes in the kitchen, where its influence is more generally appreciated. The care with which a cook exposes a dish to the heat ("heat application"), the attention given to time and rate of heating, as in boiling an egg or baking a pie, and the good results that generally follow the operation without provision for automatic control of temperature, suggest application of the same simple principles in industrial heating operations. Such procedure would do much to eliminate the irregularities so frequently disclosed by physical tests, regardless of evidence in the form of pyrometer records and analyses of material to show that such irregularities should not exist.

The viewpoint of the engineer with reference to "the rate at which heat CAN be transferred" to save time or fuel or increase production, should be considered with the views of the metallurgist or chemist in determining "the rate at which heat SHOULD be transferred" in order to effect the desired results in quality of finished product. The result of the heat-treating operation should be expressed in terms of quality and cost of finished product—not cost of fuel or labor, mere tonnage, nor indication of uniform chamber temperature.

The ideal condition for the production of uniformly heated product is nearest attained when the heating or cooling medium is uniformly applied to the entire surface of each section or piece and to each piece individually in the same manner, at the same temperature, **at the same rate, for the same time,** in the same atmosphere, in equipment properly adapted to the nature of the process, form of fuel or electricity employed, manufacturing requirements and plant conditions.

Temperature is a more or less fixed factor, determined by the nature of the process and the physical or chemical requirements of the product to be heated or cooled. It should be considered with reference to **the distinction between temperature of the chamber or bath in which a piece is exposed and the temperature throughout the piece itself,** which is naturally affected by the time of exposure and the rate of heat absorption.

Time of heating is a variable factor and is influenced by the manner of transferring heat to or from the surface of the piece; the manner of loading, or exposure; the relation of one piece to another and to the source of the heat; the difference between temperature of the piece and the chamber or bath in which it is exposed; the rate of circulation over the surface; conductivity of the material of which the piece is composed; relation of the mass of the charge to the chamber or bath in which it is exposed, and other factors outlined by Fig. 3.

Rate of heating or cooling of material must be determined with reference to the physical or chemical requirements of the finished product, and with reference to the mass, shape, section, exposed surface, and manner of exposure of the material, all of which affect the rate at which it SHOULD be heated or cooled, regardless of how fast heat COULD be transferred.

Rate of heat transfer affects the time required for heating or cooling, and exerts material influence upon quality of the finished product. It should be considered with reference to the relation of the condition inside of the piece to the sections near the surface. **The influence of variable section, shape or surface exposed upon the rate of heating or cooling** may necessitate slow heating or preheating in order that the mass may be well saturated before being subjected to the final temperature. Disregard of this point is responsible for the difficulties that frequently follow the practice of maintaining furnace temperatures materially higher than that required in the stock.

The relation of the temperature of a furnace to the temperature at the outside of a piece is not necessarily an indication of uniform structure unless the time period has been sufficient for thorough saturation and the stock properly exposed to the heat. A difference in time of exposure or manner of exposing two similar pieces at the same temperature may result in a difference in structure.

The method of loading a furnace affects the time required for heating the individual piece; the uniformity of structure of each piece throughout its mass; and the relation of the uniformity of each piece to another. The influence upon the time and rate of heating of the exposure resulting from a given manner of loading and variations in the surface, shape and section, may be illustrated by the diagrams in Fig. 4.

A round billet of given mass and weight placed on the hearth of a furnace (A) will heat less uniformly and at a different rate than if placed above the floor (B) to permit circulation underneath and uniform application of heat to the entire surface.

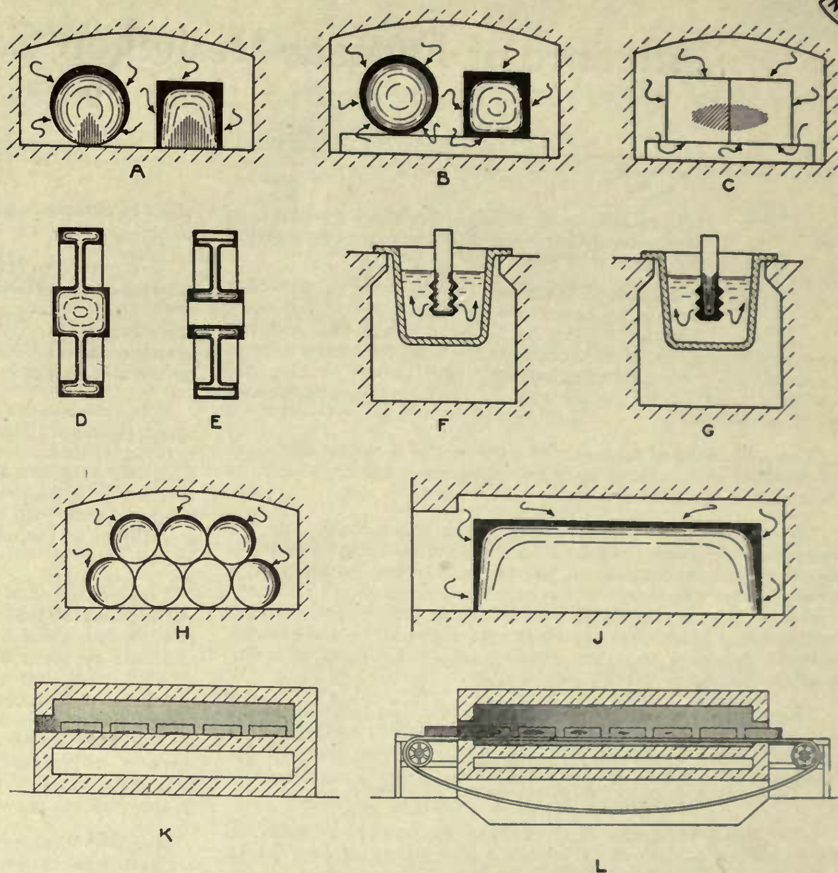


Fig. 4. Illustrations of influence of mass, surface, shape, and manner of exposure upon time and uniformity of heating.

A billet of the same mass and weight in rectangular form will heat at a different rate and to a different degree of uniformity if placed in either position on account of the relatively larger surface in proportion to the mass at the corners, which are the first to heat up and the first to cool off. Even though the shape of the rectangular billet may permit a higher rate of absorption, it is obvious that **the difference in shape may actually suggest a lower rate of heat transfer** to permit a slow rate of heating, in order to prevent a material difference in temperature or time of exposure to that temperature between the corners and center of the mass.

The same billet in the form of an irregularly shaped crankshaft or axle with variable sections will heat in a still different manner if placed in either position on account of the difference in surface and section.

A gear blank (D) will absorb heat at an entirely different rate than the finished gear (E), on account of the difference in section incident to the shape of the teeth and opening for the shaft keyway, etc.

A similar condition may result from the **relation of the pieces to each other,** even in a chamber that shows every indication of uniform temperature. Thus, two rectangular pieces placed above the floor, with provision for heat application to all surfaces, will heat at a different rate and to a different degree of uniformity when placed in contact with each other(C).

Heating in baths of molten metal, salts, etc., is generally considered to be an ideal method for operations in which uniformity of heating and temperature control are essential factors. However, the difference between heating in a molten bath and in a "bath" of gases in the chamber of a furnace is not as great as is generally supposed. The essential difference is in the influence of the bath upon the surface of the piece; the manner of exposure and the resistance of the bath to rapid transfer of heat.

The necessity for suspending the piece in a bath naturally results in an ideal condition for proper "heat application" to the surface, and eliminates many chances for error likely to result from improper methods of loading in the chamber of a furnace, particularly if it is desired to localize the heat, as in hardening the cutting section of a tool.

Inequalities of temperature may exist throughout a bath without indication by the pyrometer in its customary fixed position, as may be observed in heating the bath from a cold condition; in introducing a comparatively large mass of cold material; or when the input of cold material does not correspond with the withdrawal of heated material.

The use of a bath does not eliminate the necessity for considering the time element with reference to the factors that influence the rate of heat transfer and uniformity of heating or cooling. A difference in relation of mass and surface, due to a difference in shape or section, naturally affects the rate of heat transfer and the time required for saturation. Thus, if a tap were suspended in a bath of molten metal (F), the comparatively thin sections would reach the temperature of the bath before the center of the piece; and even though the center ultimately attains the same temperature (G), the fact remains that the thin sections have been subjected to that temperature for a longer time, which of itself is frequently sufficient to create a difference in structure.

This illustrates **the difference between uniform temperature in a furnace and uniformly heated product,** and the necessity for considering the influence of the factors that affect time or rate of heating, as well as the factors that affect control of temperature. **Uniform heating is a relative term. Absolute uniformity is rarely, if ever, attained.**

The necessity for uniform time and method of exposure and rate of heating or cooling to produce uniform product indicates the need for a method of heating, cooling and handling that will provide the same treatment for each piece.

"Batch heating" or cooling rarely results in uniform product, regardless of the indication of uniform chamber temperature, because of the lack of uniformity in method and time of exposure and rate of heating or cooling. Variation is generally disclosed by the structural difference between the pieces at the outside of the charge and those at the center or bottom.

The advantages of the continuous furnace (L) in providing a regular input and output of material, and control of the factors affecting time and rate of heating, suggest application of the principle of individual treatment whenever the manufacturing requirements and plant conditions will so permit.

The difference between control of temperature in a furnace and control of the application of heat to the product is not merely a function of controlling the input of heating energy, whether it be fuel or electricity. The manner in which the heat is applied to the surface of the piece, which very largely reflects the design and method of operating the furnace, is of paramount importance; and necessarily involves factors affecting the element of time and rate of heating and cooling, which are equally as important as factors that influence control of temperature. All of these must be considered in order to produce a product as uniform as the pyrometer indicates it should be.

Influence of Furnace Design on Cost of Production

THE ultimate cost of a finished product of given quality is governed by the rate of production and the cost of operation.

Because of the many variable factors governing the quality and cost of product (page 5), the selection of furnace equipment (page 13), and the selection of fuel (page 33), consistent efforts to reduce cost of production require a thorough study of methods of heating and handling adapted to specific manufacturing requirements and plant conditions.

The influence of furnace design on the quality and cost of product is illustrated by the diagrams on page 11, which are examples from actual practice.

These diagrams illustrate the economy attainable by the proper use of furnaces of suitable design, the selection of which is based upon consideration of the manufacturing problem as a whole. They also illustrate the economic weakness of the far too common practice of basing selection only on price or form of fuel, equipment or labor; quantity of output; temperature control, etc., without reference to other equally essential factors affecting quality and cost of the finished product.

There are no fixed standards to determine definitely the proper form of equipment or fuel to use. Each must be selected with reference to the other, and the suitability of the combination to the heating process, manufacturing requirements and plant conditions.

Frequently it is possible to better the quality of product by adapting an improved method of heating or cooling to existing conditions. A different type or arrangement of furnace equipment may decrease labor, fuel and time; utilize the floor space to better advantage; and provide more comfortable working conditions. This generally results in an increased output and lowered production cost even with the same unit prices for fuel, labor and power, and without necessarily requiring new building construction.

Requirements for quality should determine the method of heat application. With this as a basis, the production requirements and plant conditions should determine the type, size, number and arrangement of furnaces; the form of fuel or electrical energy; and the methods of routing and handling the material.

It is a common but misleading assumption that control of chamber temperature or of heat supply is synonymous with control of heated product. On the contrary, **control of the generation of heat is not equivalent to control of the application of heat, or to control of the uniformity of product.** Other essential factors (page 13) influence the ultimate result.

The difference between control of heat as it is generated in the furnace, and control of heat as it is applied to the product in the furnace, must be considered with electric as well as fuel-fired furnaces.

The comparative ease of controlling electricity, gas or oil is frequently considered as the determinative factor in the selection of heating equipment, regardless of a material difference in price of other forms of heat energy or equipment.

Automatic control of the delivery of coal through stokers or in powdered form; of gas, oil or steam through automatic valves; or of electricity through various forms of regulating devices, **may result in control of the generation of heat, but does not necessarily determine the use made of the heat.**

The question of control involves control of the supply of fuel or electricity to the furnace; control of supply of heat to the working chamber; control of the heat as it is actually applied to the surface of the product; and control of the time of exposure and the rate at which heat is transferred to the product.

Temperature is inseparably linked with time of exposure and rate of heating. The time factor must be considered with reference to the mass, surface and shape of the individual piece; the method of loading; and the rate at which heat SHOULD be transferred, as well as the rate at which heat CAN be transferred to effect economy in fuel or time of heating.

The variable factors affecting time of heating, noted on the chart, page 8, indicate the necessity of considering the time factor with regard to the result sought in quality of the finished product. The mass, surface, shape or section of the charge may suggest a slower rate of heating, from the viewpoint of the metallurgist or chemist, with regard to quality, than that possible from the standpoint of the engineer to increase output or effect economy in fuel.

The influence of furnace design upon the application and utilization of heat is far-reaching. For instance, there is a radical difference between the arc, induction, and resistance methods of generating heat by electricity. There is even a distinction within each of these broad groups. With the resistance method, for example, the heat may be generated by means of metallic resistors distributed on the walls of the furnace or by other forms of resistance material the nature of which prohibit such distribution. In each instance the furnace design must be adapted to the method of generating and delivering heat to the working chamber.

It is thus apparent that **the practice of associating a given form of fuel or electricity with quality or low cost of production is misleading, unless there is definite reference to the form of furnace and method of heat application and utilization.**

This fact may be illustrated by an unusual case which involved a comparatively efficient type of furnace fired manually with bituminous coal, and three less efficient furnaces, one fired with oil, another with natural gas and the third heated electrically through metallic resistors with suitable control devices. **With all other conditions substantially alike, it was conclusively proved that the quality and cost of the product were most favorable with the coal-fired furnace.**

This example, however, does not prove that any one method of generating heat is superior. In this instance **the difference in results was due to the better design and operation of the coal-fired furnace,** and the manner of applying and utilizing heat in the product. In one case, the apparent disadvantage of a crude form of fuel was overcome by an efficient furnace, while in the others, the apparent advantages of the more flexible forms of fuel, and particularly the advantage of electricity with control devices, were neutralized by inefficient furnaces.

Other heat-treatment processes, manufacturing requirements or plant conditions might prohibit any three of these methods of generating heat; and the most expensive form of heat energy in combination with a suitable furnace might show better results at less cost.

There is no one form of fuel, electricity or furnace suitable for all conditions—but there undoubtedly is a suitable combination which, when properly used, will best meet the requirements of each case.

Cost of production cannot be definitely expressed in terms of output per operative, per unit of fuel, time or floor space. **It is actually determined by quality and ultimate cost,** which include many intangible factors difficult to measure. It is greatly influenced by the nature of equipment and the skill and intelligence of the operatives. Improvement will begin with proper selection and use of furnace equipment properly adapted to the heat-treating process, manufacturing requirements, and plant conditions.

INFLUENCE OF FURNACE DESIGN ON COST OF PRODUCTION

EXAMPLES FROM PRACTICE, ILLUSTRATING THE ECONOMY EFFECTED BY PROPER SELECTION AND USE OF FURNACES OF IMPROVED DESIGN, ADAPTED TO MANUFACTURING REQUIREMENTS AND PLANT CONDITIONS

D-12
1221

SMALL DROP FORGE FURNACE OPERATION

OUTPUT PER UNIT OF FLOOR SPACE - 37% INCREASE

OUTPUT PER UNIT OF FUEL - 78% INCREASE

SMALL DROP FORGE FURNACE OPERATION

OUTPUT PER UNIT OF FLOOR SPACE - 275% INCREASE

OUTPUT PER UNIT OF FUEL - 27% INCREASE

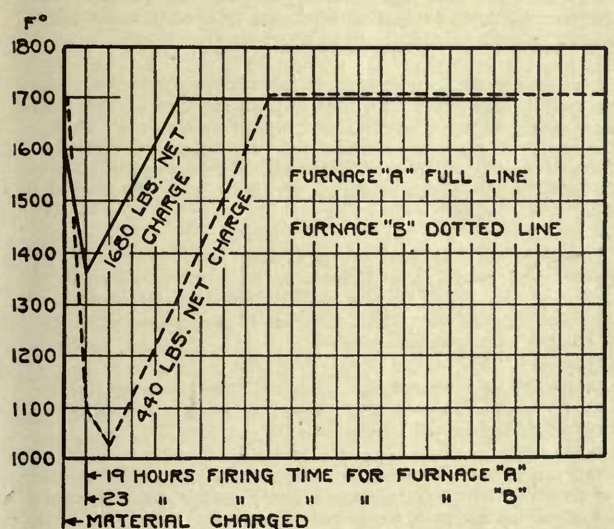
HEAT-TREATING DROP FORGED STEEL PARTS

OUTPUT PER MAN - 100% INCREASE

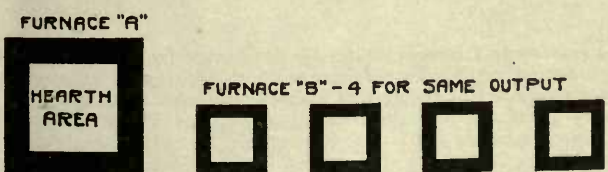
OUTPUT PER UNIT OF FLOOR SPACE - 17% INCREASE

OUTPUT PER UNIT OF FUEL - 33% INCREASE

CARBONIZING AUTOMOBILE PARTS



TEMPERATURE & TIME OF HEATING PERIOD



EQUIVALENT HEARTH AREA, - FLOOR SPACE AND RELATIVE WALL THICKNESS

OUTPUT PER UNIT OF FUEL - 90% INCREASE WITH FURNACE "A" OVER FURNACES "B".

SMALL DROP FORGE FURNACE OPERATION

OUTPUT PER UNIT OF FLOOR SPACE - 250% INCREASE

OUTPUT PER UNIT OF FUEL - 47% INCREASE

DROP FORGE FURNACE OPERATION

TIME FROM LIGHTING FURNACE TO STARTING FORGING 39% DECREASE

OUTPUT PER HOUR - 43% INCREASE

OUTPUT PER UNIT OF FUEL - 90% INCREASE

HARDENING SMALL HIGH CARBON STEEL PARTS

OUTPUT PER MAN - 140% INCREASE

OUTPUT PER UNIT OF FLOOR SPACE - 50% INCREASE

QUALITY - REJECTIONS REDUCED FROM 5% TO .076%

ANNEALING PRESSED STEEL PARTS

OUTPUT PER MAN - 75% INCREASE

OUTPUT PER UNIT OF FLOOR SPACE - 103% INCREASE

OUTPUT PER UNIT OF FUEL - 25% INCREASE

AUTOMATIC END ANNEALING OF SMALL BRASS TUBES

OUTPUT PER MAN - 200% INCREASE

OUTPUT PER UNIT OF FLOOR SPACE - 8% INCREASE

QUALITY - REJECTIONS REDUCED FROM 5% TO 1%

AUTOMATIC END ANNEALING OF LARGE BRASS TUBES

OUTPUT PER MAN - 275% INCREASE

OUTPUT PER UNIT OF FLOOR SPACE - 280% INCREASE

QUALITY - REJECTIONS REDUCED FROM 10% TO 1%

CHEMICAL OXIDATION OF METALLIC POWDER

OUTPUT PER MAN - 650% INCREASE

OUTPUT PER UNIT OF FLOOR SPACE - 1110% INCREASE

QUALITY - OXIDATION INCREASED FROM 88% TO 93%.

Fig. 5

Selection of Furnaces

THE selection of industrial heating equipment, which must be coincident with the selection of a suitable form of heat energy (combustible or electric), resolves itself into the problem of determining the type, design, size, number and arrangement of furnaces and auxiliary equipment necessary to meet specific plant conditions, and of providing the most efficient methods of heating, cooling, routing and handling the material.

The physical or chemical nature of the heat-treatment process; the requirements of quality; rate and quantity of production; plant conditions and cost of operation are basic factors which influence selection. There are many other factors of varying importance, outlined by the chart on page 13, any one of which may also influence the selection and arrangement of equipment or the cost of production.

Uniformity of heating and cooling, and the relationship of temperature, atmosphere, rate and time of heating and cooling to the surface exposure and mass of product, are governed by natural laws which cannot be ignored without sacrifice in quality or quantity of product or economy of operation.

Selection is largely a matter of compromise in reconciling requirements of quality with others related to methods of heating and handling, output, plant conditions and cost of production.

Standardization of furnaces as to type, design and size, to the extent common with boilers, engines, motors, machine tools, etc., is impracticable because of the endless variety of individual requirements. Such requirements usually involve differences in size, shape, weight or composition of materials; quantity and rate of flow; processes; methods of heating, cooling, routing and handling of material; arrangement of equipment; floor space; hours of operation; forms of fuel available; etc. **To meet such conditions there must be corresponding variety in design and size of furnaces.**

There is no more reason to assume that one form of fuel, electricity, or furnace may be adapted to all industrial heating requirements, than to assume that one type of dwelling or factory would meet all building requirements, or that one form of prime mover would meet all requirements for power.

The difficulty of definitely measuring heating results, unlike measuring results in power, illumination or transportation, **adds to the complication** because **appraisement of furnace performance must be based on quality and cost of product and the method of operation under specific plant conditions.**

Temperature control, price or quantity of fuel, composition of gases, etc., are merely contributing factors, and bear about the same relation to industrial heating as they bear to the operation of a motor truck.

The "heat unit" (B. t. u.) standard for judging fuel values and "heat balance" for testing furnace performance are incomplete and misleading, except for comparing fuels of the same physical and chemical characteristics, and furnaces of the same mechanical characteristics, operated under identical conditions of applying and utilizing heat and of loading and handling material. The "heat unit value" of a fuel, like the "heat balance" of a furnace, is but one indication of economic value.

It is misleading to compare coal, oil, gas or electricity without considering their form characteristics and the differences in the mechanical form and operation of the furnaces or other appliances adapted to their use. Likewise, it is misleading to compare fuels of the same physical form, such as clean producer gas, water gas, city gas, natural gas, acetylene gas, etc., without considering differences in chemical composition, combustible mixture, products of combustion and calorific intensity of heat release. **Consideration must be given to the influence of furnace design and operation upon the temperature and atmosphere, and upon the uniformity and cost of product.**

Electricity must be considered with regard to its "form value" in determining its field of usefulness. A difference in current (alternating or direct), or in voltage, phase or cycle; the difference between arc, resistance and induction methods of releasing heat, and the effect upon the product of differences in the atmosphere set up in releasing the heat, must be considered in relation to individual requirements.

The common practice of comparing inefficient furnaces, unsuited to the specific manufacturing conditions and improperly operated, **with furnaces of a suitable type,** more efficiently operated, using another form of fuel, and crediting the improved results to the difference in form of fuel or heat energy, is largely responsible for mistakes in the selection of both furnaces and fuels.

The "form value" of fuel or heat energy must be considered with the design and operation of the furnace. Very often a fuel requires a particular type of furnace to enable it to do certain work. Producer gas, for instance, is unsuited for melting steel except in a regenerative furnace. Electricity with the resistance method of releasing heat may be used to accomplish a result not possible with the arc method, or vice versa.

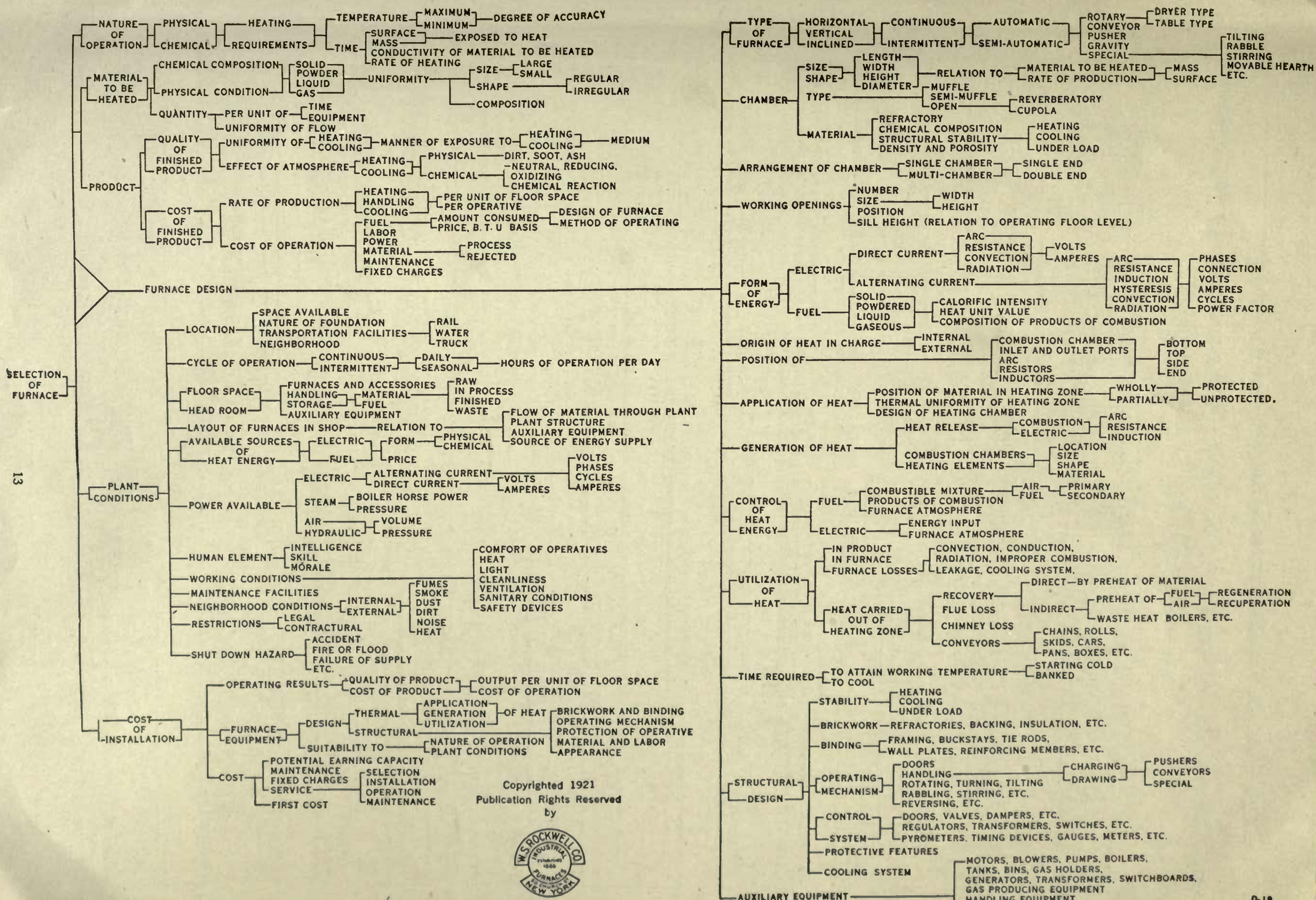
It is unreasonable to compare an intermittently operated or "batch type" regenerative furnace with a furnace of the continuous non-regenerative type, or to compare continuous furnaces of different types, or single-chamber with multi-chamber furnaces, even though the "heat balance" be identical, unless each affords equally efficient means for applying the heat and handling the product.

A difference in method of applying heat or handling material may result in a difference in quality or cost of product that would not be disclosed by consideration solely of heat balance, fuel consumption, analysis of flue gases or indication of chamber temperature control.

No one type of furnace or form of heat energy (combustible or electric) has a monopoly on uniformity of heating or economy of operation.

Furnaces and fuels should be selected for the useful service they can render when properly employed under specific conditions, and with due regard to their form as well as price. Each should be selected on its merits, judged by the factors outlined in the chart. Their use is but a means to an end, **the economic value of which is measured by the resulting quality and cost of the finished product or service,** and not by any one phase of their performance.

The variety in furnace design is illustrated by the accompanying diagrams of Rockwell furnaces, which have been developed during many years of practice in different branches of industry. Virtually all of the furnaces illustrated, each of which has its field of usefulness as well as its limitations, have been built in different sizes with varying methods of heat application, arrangement of chambers, working openings, etc., for the use of different fuels and electricity, to meet a wide range of heating processes, manufacturing requirements and plant conditions. They illustrate the endless variety of methods of applying in practice the principles that govern the production of heat-treated products, and the necessity for considering each case on its merits and in light of the development resulting from practice.


SELECTION OF FURNACE
NATURE OF OPERATION
PHYSICAL
CHEMICAL
HEATING
REQUIREMENTS
TEMPERATURE
MAXIMUM
MINIMUM
DEGREE OF ACCURACY
TIME
SURFACE
MASS
EXPOSED TO HEAT
CONDUCTIVITY OF MATERIAL TO BE HEATED
RATE OF HEATING
MATERIAL TO BE HEATED
CHEMICAL COMPOSITION
PHYSICAL CONDITION
SOLID
POWDER
LIQUID
GAS
UNIFORMITY
SIZE
LARGE
SMALL
SHAPE
REGULAR
IRREGULAR
COMPOSITION
QUANTITY
PER UNIT OF
TIME
EQUIPMENT
UNIFORMITY OF FLOW
PRODUCT
QUALITY OF FINISHED PRODUCT
UNIFORMITY OF
HEATING
COOLING
MANNER OF EXPOSURE TO
HEATING
COOLING
MEDIUM
EFFECT OF ATMOSPHERE
HEATING
COOLING
PHYSICAL
DIRT, SOOT, ASH
CHEMICAL
NEUTRAL, REDUCING,
OXIDIZING
CHEMICAL REACTION
COST OF FINISHED PRODUCT
RATE OF PRODUCTION
HEATING
HANDLING
COOLING
PER UNIT OF FLOOR SPACE
PER OPERATIVE
COST OF OPERATION
FUEL
LABOR
POWER
MATERIAL
MAINTENANCE
FIXED CHARGES
AMOUNT CONSUMED
PRICE, B. T. U BASIS
DESIGN OF FURNACE
METHOD OF OPERATING
PROCESS
REJECTED
FURNACE DESIGN
PLANT CONDITIONS
LOCATION
SPACE AVAILABLE
NATURE OF FOUNDATION
TRANSPORTATION FACILITIES
NEIGHBORHOOD
RAIL
WATER
TRUCK
CYCLE OF OPERATION
CONTINUOUS
INTERMITTENT
DAILY
SEASONAL
HOURS OF OPERATION PER DAY
FLOOR SPACE
HEAD ROOM
FURNACES AND ACCESSORIES
HANDLING
STORAGE
AUXILIARY EQUIPMENT
MATERIAL
FUEL
RAW
IN PROCESS
FINISHED
WASTE
LAYOUT OF FURNACES IN SHOP
RELATION TO
FLOW OF MATERIAL THROUGH PLANT
PLANT STRUCTURE
AUXILIARY EQUIPMENT
SOURCE OF ENERGY SUPPLY
AVAILABLE SOURCES OF HEAT ENERGY
ELECTRIC
FUEL
FORM
PHYSICAL
CHEMICAL
PRICE
POWER AVAILABLE
ELECTRIC
ALTERNATING CURRENT
DIRECT CURRENT
VOLTS
AMPERES
VOLTS
PHASES
CYCLES
AMPERES
STEAM
BOILER HORSE POWER
PRESSURE
AIR
HYDRAULIC
VOLUME
PRESSURE
HUMAN ELEMENT
INTELLIGENCE
SKILL
MORALE
WORKING CONDITIONS
COMFORT OF OPERATIVES
HEAT
LIGHT
CLEANLINESS
VENTILATION
SANITARY CONDITIONS
SAFETY DEVICES
MAINTENANCE FACILITIES
NEIGHBORHOOD CONDITIONS
INTERNAL
EXTERNAL
FUMES
SMOKE
DUST
DIRT
NOISE
HEAT
RESTRICTIONS
LEGAL
CONTRACTURAL
SHUT DOWN HAZARD
ACCIDENT
FIRE OR FLOOD
FAILURE OF SUPPLY
ETC.
COST OF INSTALLATION
OPERATING RESULTS
QUALITY OF PRODUCT
COST OF PRODUCT
OUTPUT PER UNIT OF FLOOR SPACE
COST OF OPERATION
FURNACE EQUIPMENT
DESIGN
THERMAL
STRUCTURAL
APPLICATION
GENERATION
UTILIZATION
OF HEAT
BRICKWORK AND BINDING
OPERATING MECHANISM
PROTECTION OF OPERATIVE
MATERIAL AND LABOR
APPEARANCE
SUITABILITY TO
NATURE OF OPERATION
PLANT CONDITIONS
COST
POTENTIAL EARNING CAPACITY
MAINTENANCE
FIXED CHARGES
SERVICE
FIRST COST
SELECTION
INSTALLATION
OPERATION
MAINTENANCE
TYPE OF FURNACE
HORIZONTAL
VERTICAL
INCLINED
CONTINUOUS
INTERMITTENT
AUTOMATIC
SEMI-AUTOMATIC
ROTARY
CONVEYOR
PUSHER
GRAVITY
SPECIAL
DRYER TYPE
TABLE TYPE
TILTING
RABBLE
STIRRING
MOVABLE HEARTH
ETC.
CHAMBER
SIZE
SHAPE
LENGTH
WIDTH
HEIGHT
DIAMETER
RELATION TO
MATERIAL TO BE HEATED
RATE OF PRODUCTION
MASS
SURFACE
TYPE
MUFFLE
SEMI-MUFFLE
OPEN
REVERBERATORY
CUPOLA
MATERIAL
REFRACTORY
CHEMICAL COMPOSITION
STRUCTURAL STABILITY
DENSITY AND POROSITY
HEATING
COOLING
UNDER LOAD
ARRANGEMENT OF CHAMBER
SINGLE CHAMBER
MULTI-CHAMBER
SINGLE END
DOUBLE END
WORKING OPENINGS
NUMBER
SIZE
POSITION
SILL HEIGHT (RELATION TO OPERATING FLOOR LEVEL)
WIDTH
HEIGHT
FORM OF ENERGY
ELECTRIC
DIRECT CURRENT
ARC
RESISTANCE
CONVECTION
RADIATION
VOLTS
AMPERES
ALTERNATING CURRENT
ARC
RESISTANCE
INDUCTION
HYSTERESIS
CONVECTION
RADIATION
PHASES
CONNECTION
VOLTS
AMPERES
CYCLES
POWER FACTOR
FUEL
SOLID
POWDERED
LIQUID
GASEOUS
CALORIFIC INTENSITY
HEAT UNIT VALUE
COMPOSITION OF PRODUCTS OF COMBUSTION
ORIGIN OF HEAT IN CHARGE
INTERNAL
EXTERNAL
POSITION OF
COMBUSTION CHAMBER
INLET AND OUTLET PORTS
ARC
RESISTORS
INDUCTORS
BOTTOM
TOP
SIDE
END
APPLICATION OF HEAT
POSITION OF MATERIAL IN HEATING ZONE
THERMAL UNIFORMITY OF HEATING ZONE
DESIGN OF HEATING CHAMBER
WHOLLY
PARTIALLY
PROTECTED
UNPROTECTED.
GENERATION OF HEAT
HEAT RELEASE
COMBUSTION
ELECTRIC
ARC
RESISTANCE
INDUCTION
COMBUSTION CHAMBERS
HEATING ELEMENTS
LOCATION
SIZE
SHAPE
MATERIAL
CONTROL OF HEAT ENERGY
FUEL
COMBUSTIBLE MIXTURE
PRODUCTS OF COMBUSTION
FURNACE ATMOSPHERE
AIR
FUEL
PRIMARY
SECONDARY
ELECTRIC
ENERGY INPUT
FURNACE ATMOSPHERE
UTILIZATION OF HEAT
IN PRODUCT
IN FURNACE
FURNACE LOSSES
CONVECTION, CONDUCTION,
RADIATION, IMPROPER COMBUSTION,
LEAKAGE, COOLING SYSTEM.
HEAT CARRIED OUT OF HEATING ZONE
RECOVERY
FLUE LOSS
CHIMNEY LOSS
CONVEYORS
DIRECT—BY PREHEAT OF MATERIAL
INDIRECT
PREHEAT OF
FUEL
AIR
REGENERATION
RECUPERATION
WASTE HEAT BOILERS, ETC.
CHAINS, ROLLS,
SKIDS, CARS,
PANS, BOXES, ETC.
TIME REQUIRED
TO ATTAIN WORKING TEMPERATURE
TO COOL
STARTING COLD
BANKED
STRUCTURAL DESIGN
STABILITY
HEATING
COOLING
UNDER LOAD
BRICKWORK—REFRACTORIES, BACKING, INSULATION, ETC.
BINDING
FRAMING, BUCKSTAYS, TIE RODS,
WALL PLATES, REINFORCING MEMBERS, ETC.
OPERATING MECHANISM
DOORS
HANDLING
ROTATING, TURNING, TILTING
RABBLING, STIRRING, ETC.
REVERSING, ETC.
CHARGING
DRAWING
PUSHERS
CONVEYORS
SPECIAL
CONTROL
SYSTEM
DOORS, VALVES, DAMPERS, ETC.
REGULATORS, TRANSFORMERS, SWITCHES, ETC.
PYROMETERS, TIMING DEVICES, GAUGES, METERS, ETC.
PROTECTIVE FEATURES
COOLING SYSTEM
AUXILIARY EQUIPMENT
MOTORS, BLOWERS, PUMPS, BOILERS,
TANKS, BINS, GAS HOLDERS,
GENERATORS, TRANSFORMERS, SWITCHBOARDS,
GAS PRODUCING EQUIPMENT
HANDLING EQUIPMENT.
W. S. ROCKWELL CO.
INDUSTRIAL FURNACES
NEW YORK

D-19

HEATING FURNACES

LIGHT AND HEAVY FORGING – WELDING – TUBE BRAZING – RIVET, PLATE, ANGLE AND BILLET HEATING – CONTINUOUS SLUG, BILLET AND ROD HEATING

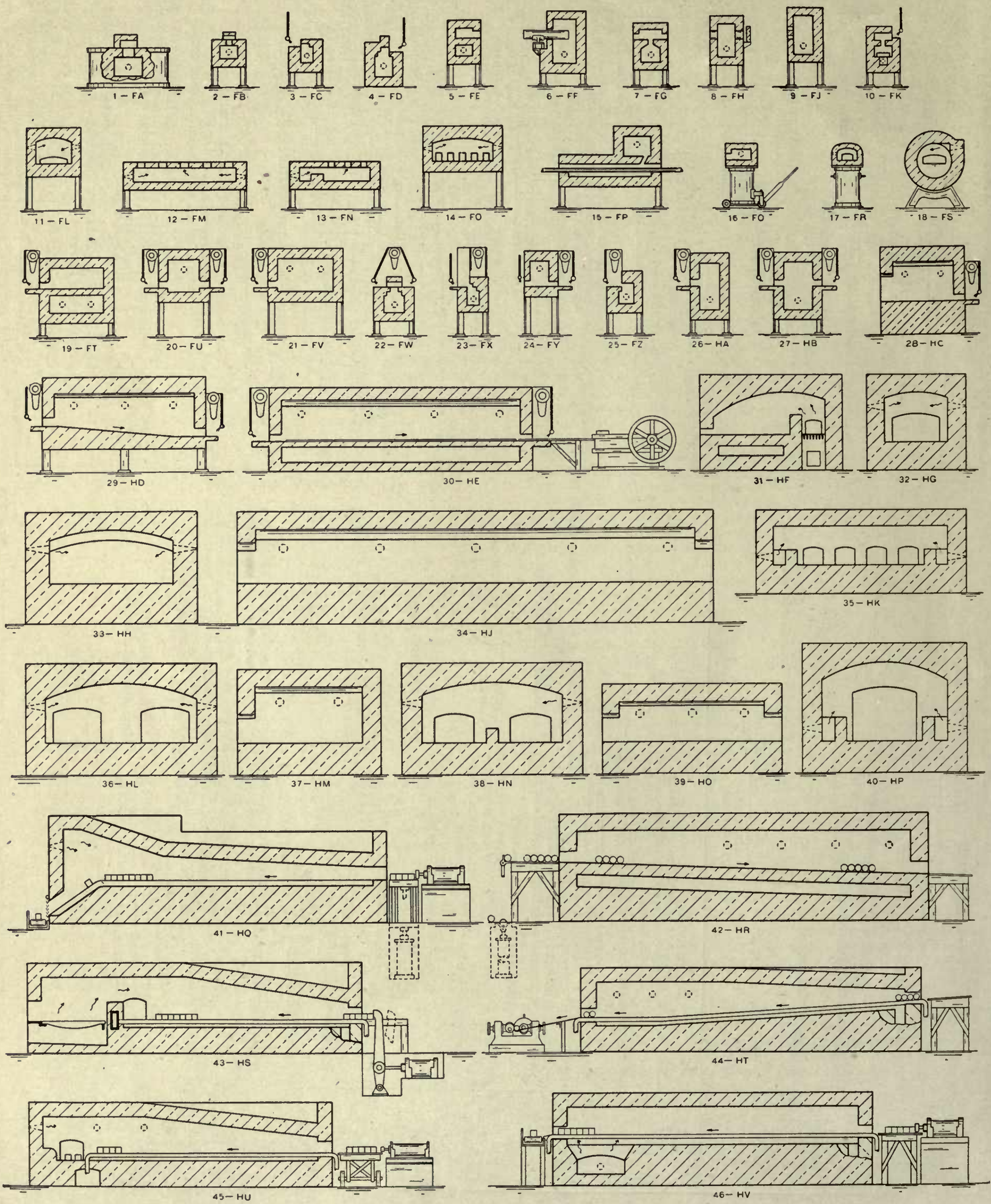
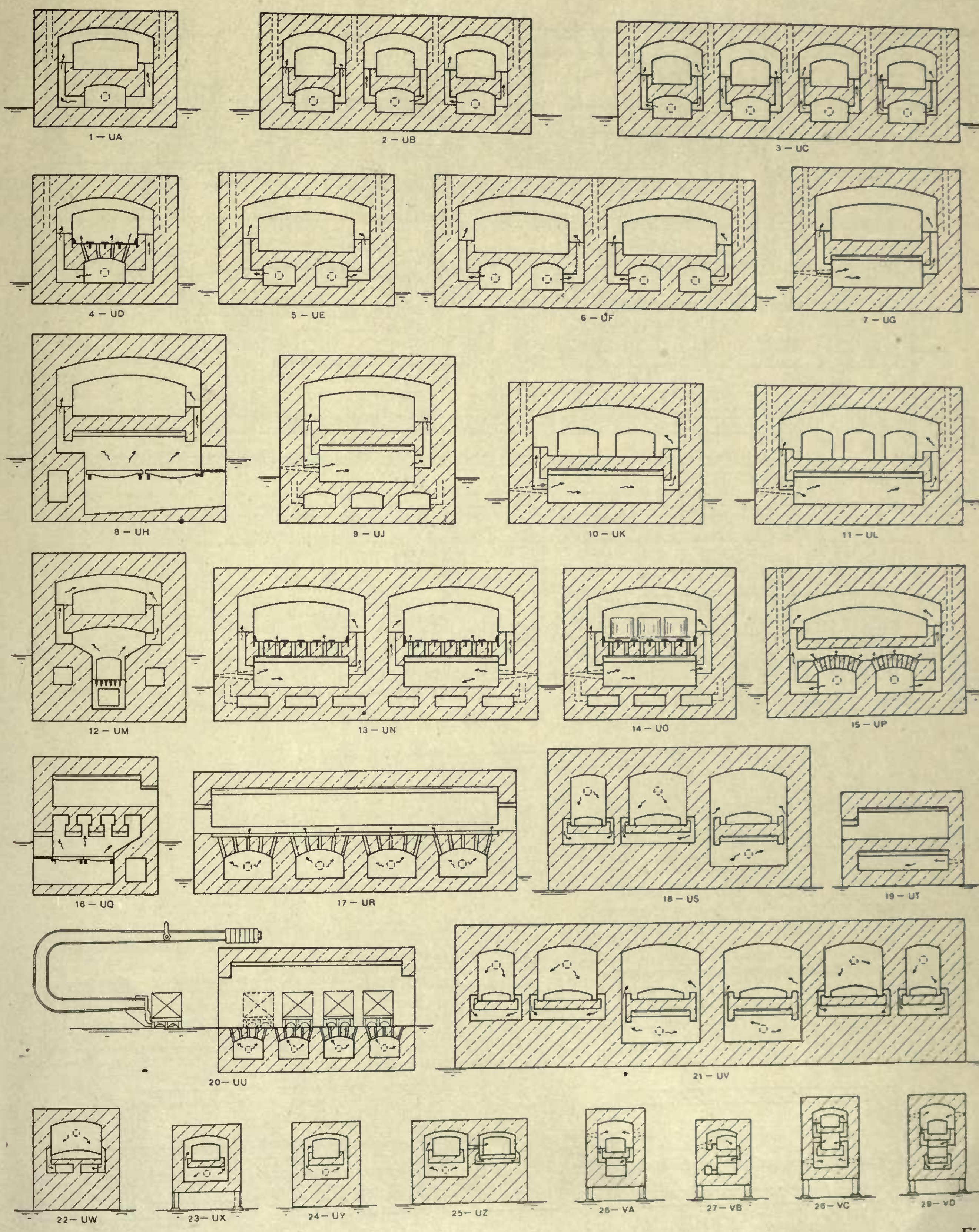


Fig. 7

ANNEALING AND HEAT-TREATING FURNACES

HARDENING — TEMPERING — CARBONIZING — SHEET, ROD, WIRE AND TUBE MILL ANNEALING — SPRING FITTING — HIGH SPEED STEEL HARDENING



ANNEALING AND HEAT-TREATING FURNACES

SHEET, ROD, WIRE AND TUBE MILL ANNEALING — CIRCULAR SAW AND PLATE HARDENING WITH PREHEATING CHAMBER — PUSHER, PAN PULLER AND CONTINUOUS LIVE ROLL ANNEALING AND HEAT-TREATING — PACK ANNEALING IN TUBES WITH CHARGING TRUCK

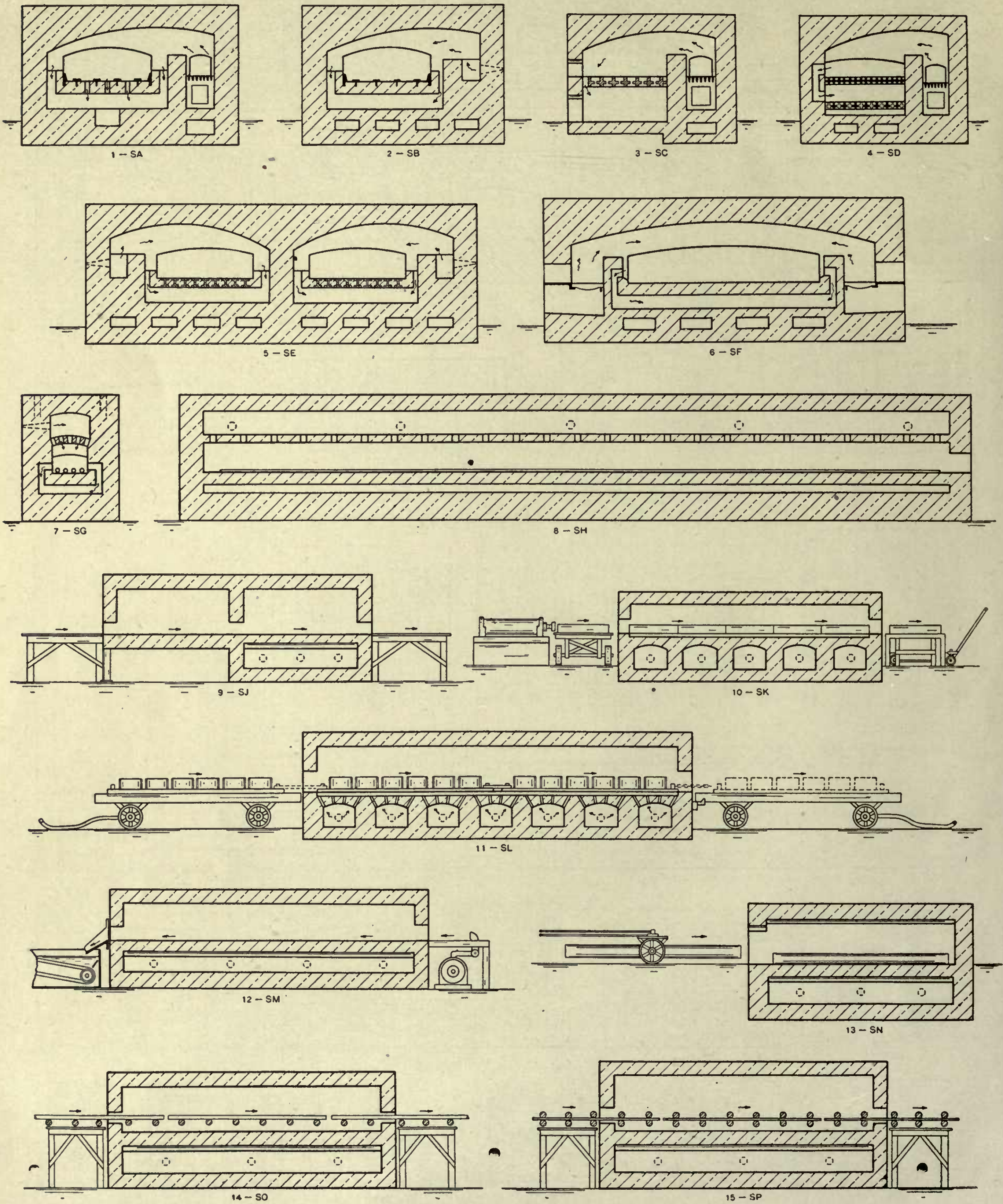


Fig. 9

CAR-AND-BALL AND CAR TYPE FURNACES

DRYING — BAKING — BLUING — JAPANNING — CORE OVENS — HEAT-TREATING SHAFTS AND LARGE IRREGULAR FORGINGS AND CASTINGS — MISCELLANEOUS MATERIAL PACKED IN POTS OR BOXES FOR BRIGHT ANNEALING, ETC.

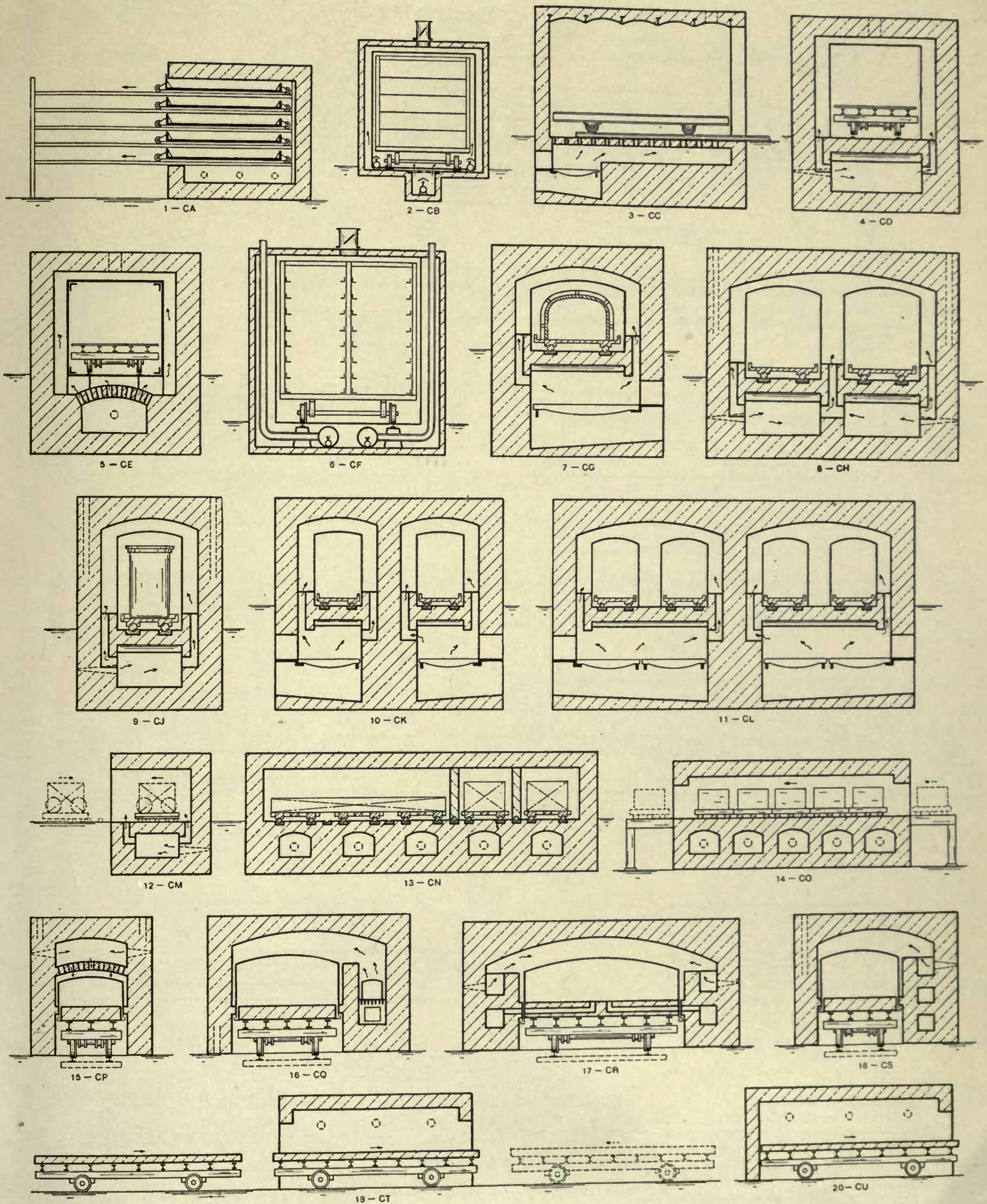
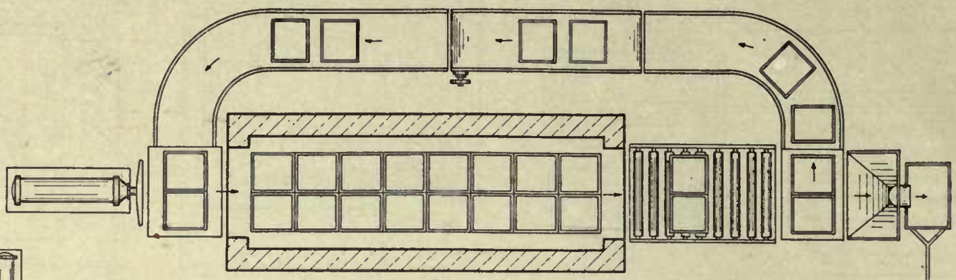


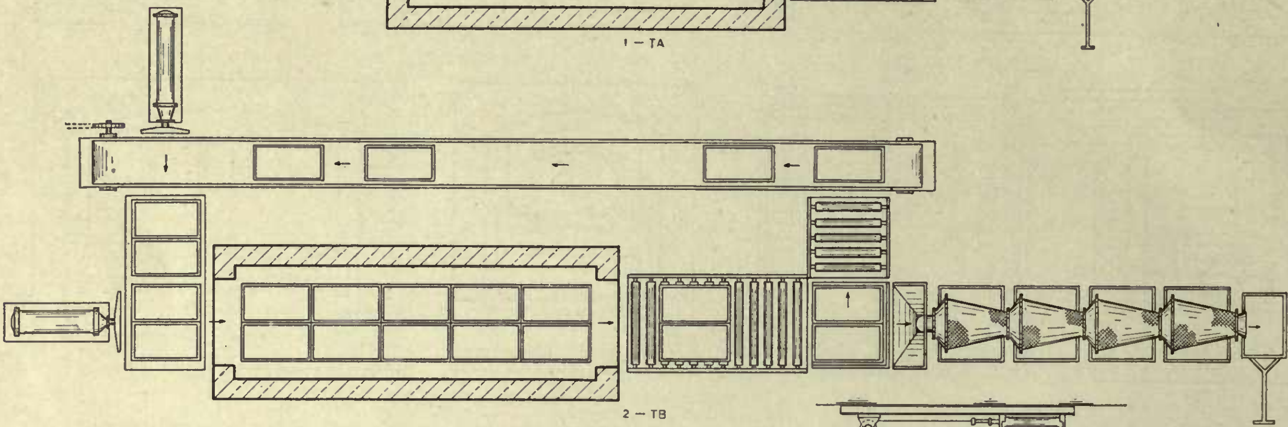
Fig. 10

CONTINUOUS ANNEALING AND HEAT-TREATING FURNACES

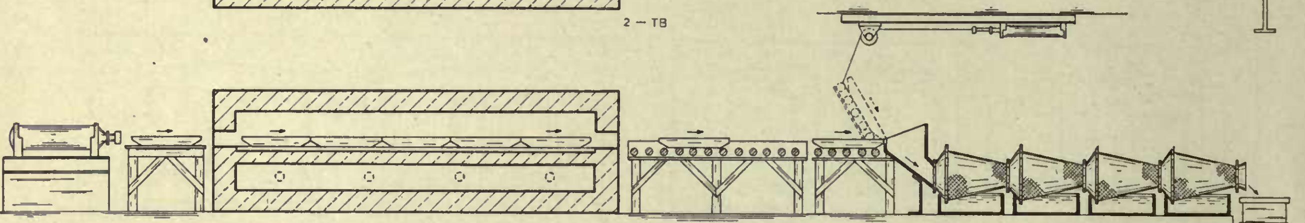
PUSHER TYPES FOR ANNEALING SMALL PARTS IN PANS. WITH COOLING TABLE. MECHANICAL DUMP INTO PICKLING MACHINE OR TRUCK. WITH CONVEYOR RETURN OF PANS TO CHARGING END — CONVEYOR AND PUSHER TYPES FOR A SEQUENCE OF HEATING AND COOLING OPERATIONS



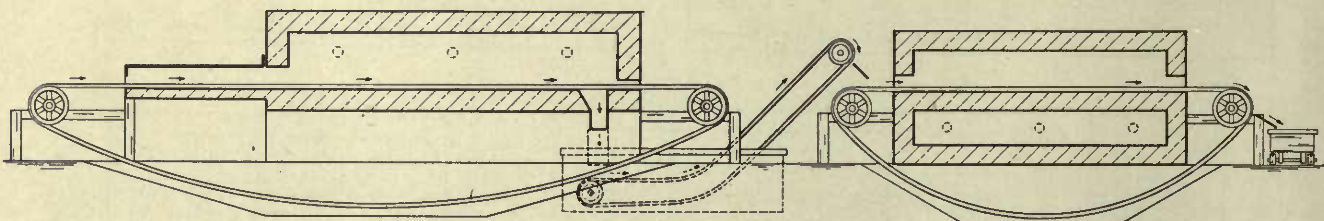
1 — TA



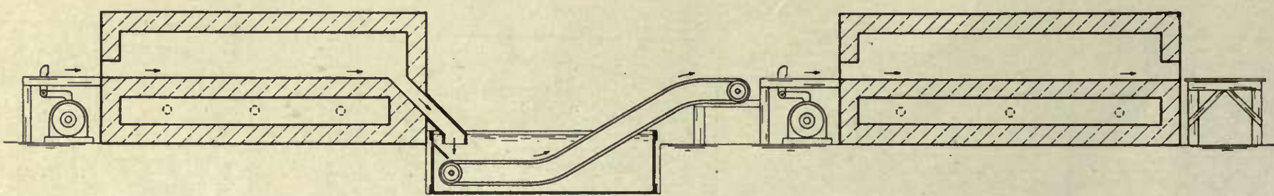
2 — TB



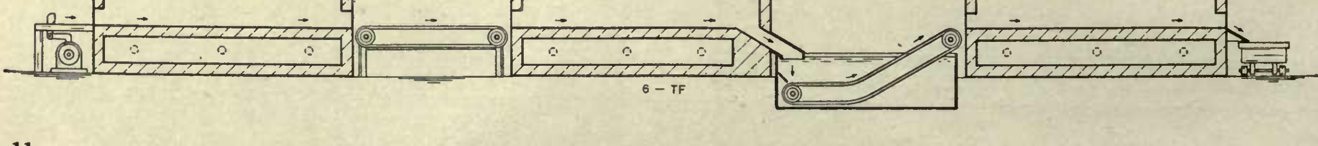
3 — TC



4 — TD



5 — TE

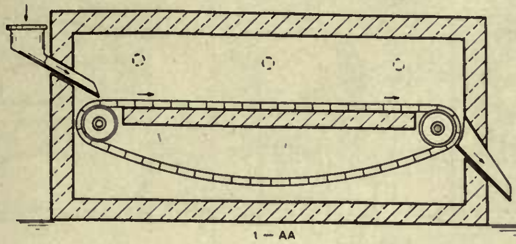


6 — TF

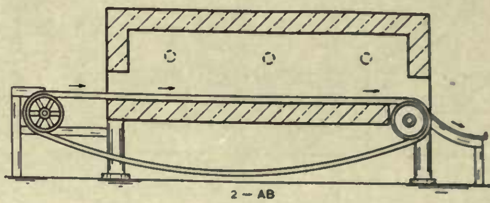
Fig. 11

AUTOMATIC CONVEYOR FURNACES

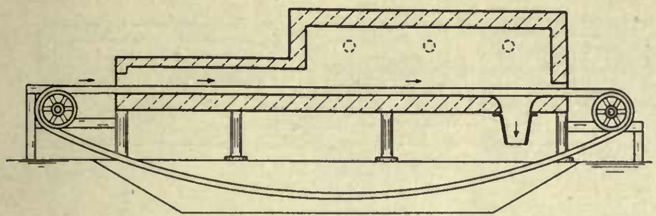
CARRY-THROUGH, INSIDE DISCHARGE AND SIDE TAKE-OUT TYPES FOR DRYING, ANNEALING, HARDENING AND TEMPERING — ALSO FOR VERTICAL AND HORIZONTAL END HEATING AND FOR STRIP ANNEALING



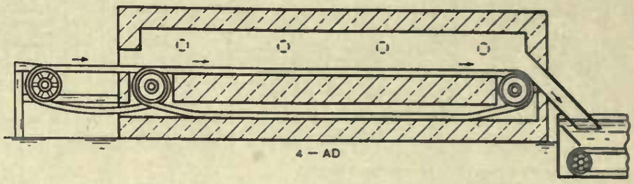
1 — AA



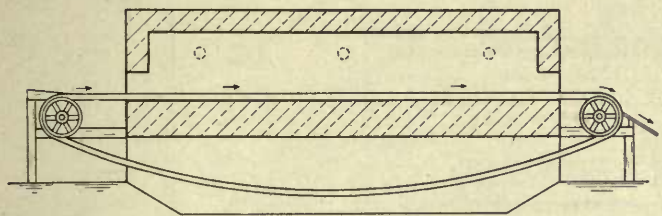
2 — AB



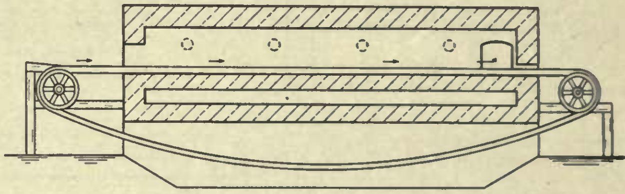
3 — AC



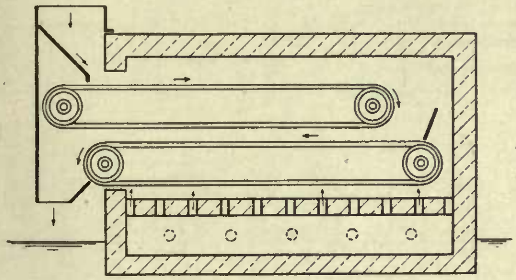
4 — AD



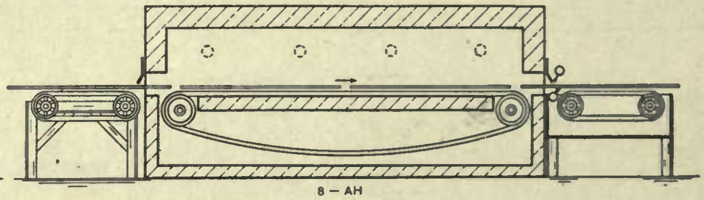
5 — AE



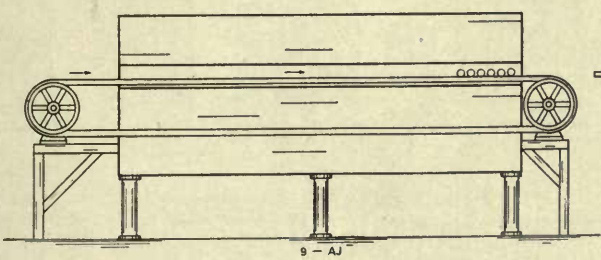
6 — AF



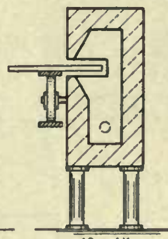
7 — AG



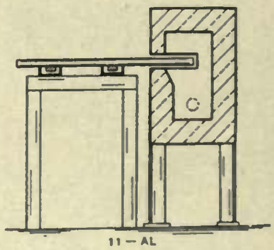
8 — AH



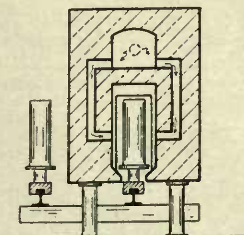
9 — AJ



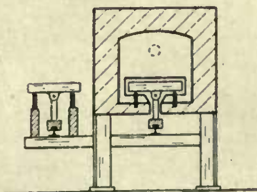
10 — AK



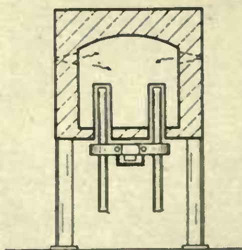
11 — AL



12 — AM



13 — AN



14 — AO

Fig. 1

MUFFLE, RETORT AND POT FURNACES

DIRECT-FIRED AND MUFFLE TYPES FOR ENAMELING, CUPELLING, RETORT ANNEALING AND HEAT-TREATING— AIR AND GAS HEATING – GALVANIZING AND TINNING – CYANIDE, LEAD, SALT AND OIL BATHS – SOFT METAL MELTING – MISCELLANEOUS CHEMICAL, LIQUID BOILING AND SIMILAR OPERATIONS

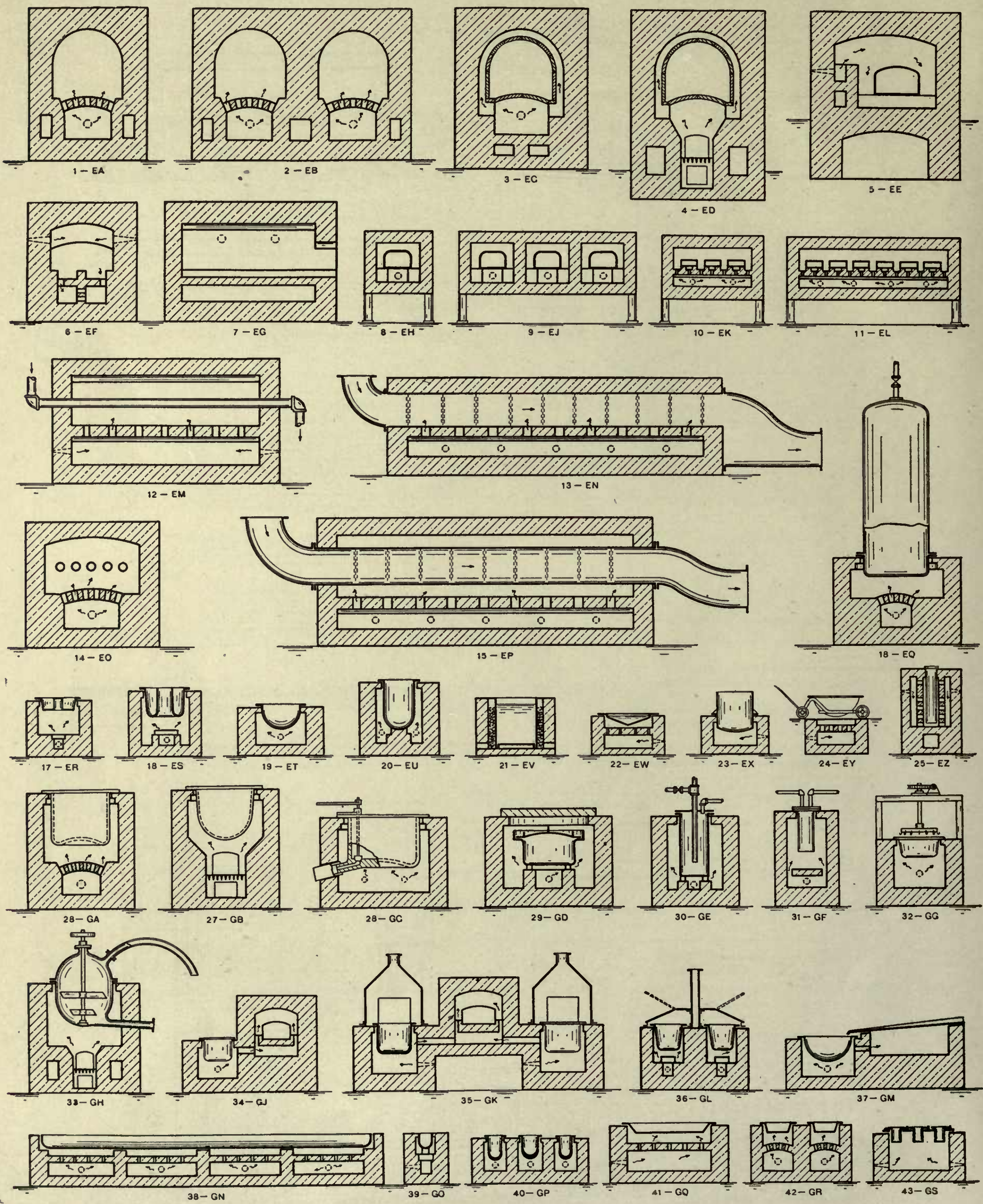
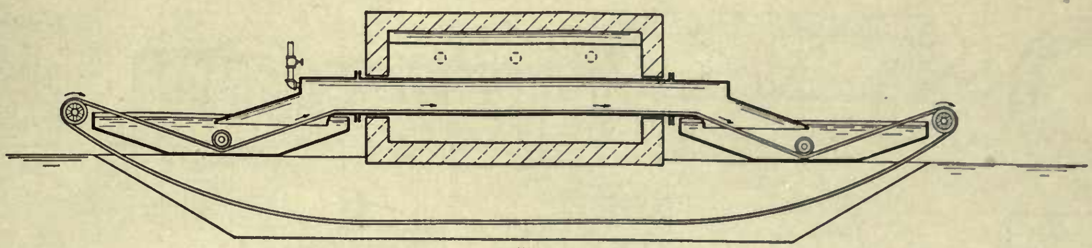


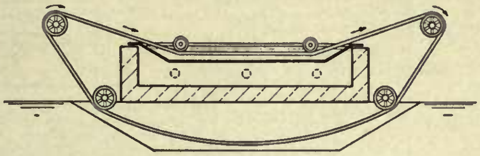
Fig. 13

CONTINUOUS ANNEALING AND HEAT-TREATING FURNACES

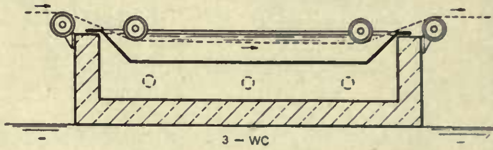
BRIGHT ANNEALING FOR COPPER — OIL AND LEAD TEMPERING — WIRE PATENTING — TINNING FOR STRIP, WIRE AND SHEET — HARDENING AND TEMPERING IN SEQUENCE — OPEN FLAME AND PLATE TYPE CLOTH SINGEING



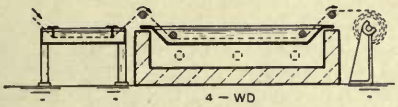
1 — WA



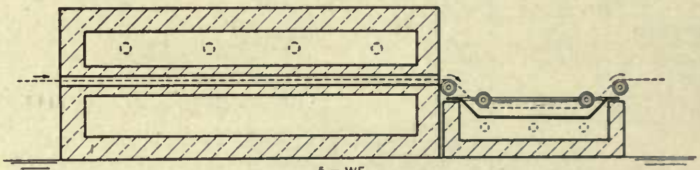
2 — WB



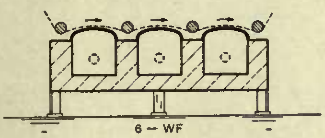
3 — WC



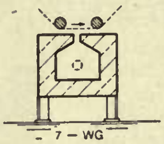
4 — WD



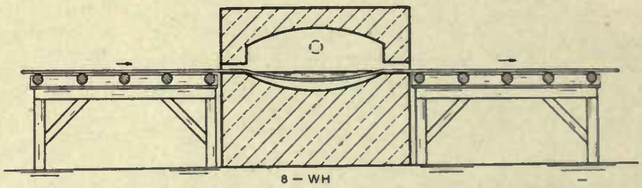
5 — WE



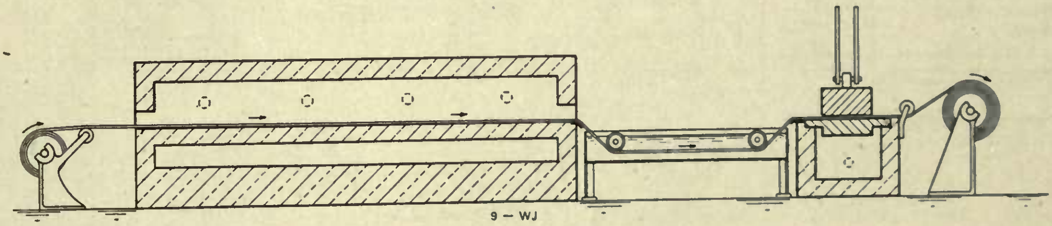
6 — WF



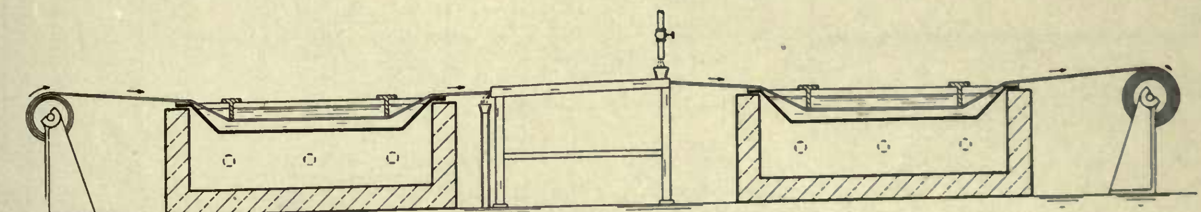
7 — WG



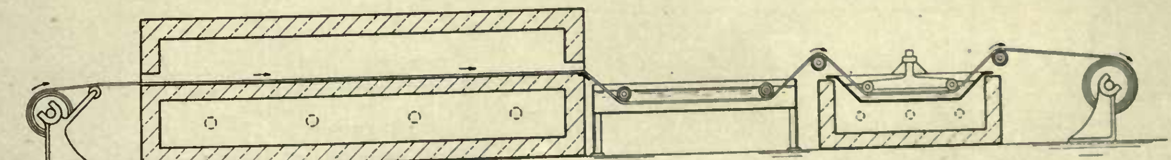
8 — WH



9 — WJ



10 — WK



11 — WL

ANNEALING, HEAT-TREATING AND PROCESSING FURNACES

DRYING — PLATE AND SAW TEMPERING IN SHAPE-RETAINING DIES — ROTATING HEARTH TYPES, WITH MANUAL OR AUTOMATIC SIDE OR CENTER DISCHARGE — ROTARY CARBONIZING — REVOLVING DRUM, SCREW CONVEYOR AND RABBLING TYPES FOR PROCESSING — REMOVABLE ROOF TYPE FOR ANNEALING, HARDENING, TEMPERING AND SHRINKING — LIVE ROLL TIRE HEATING

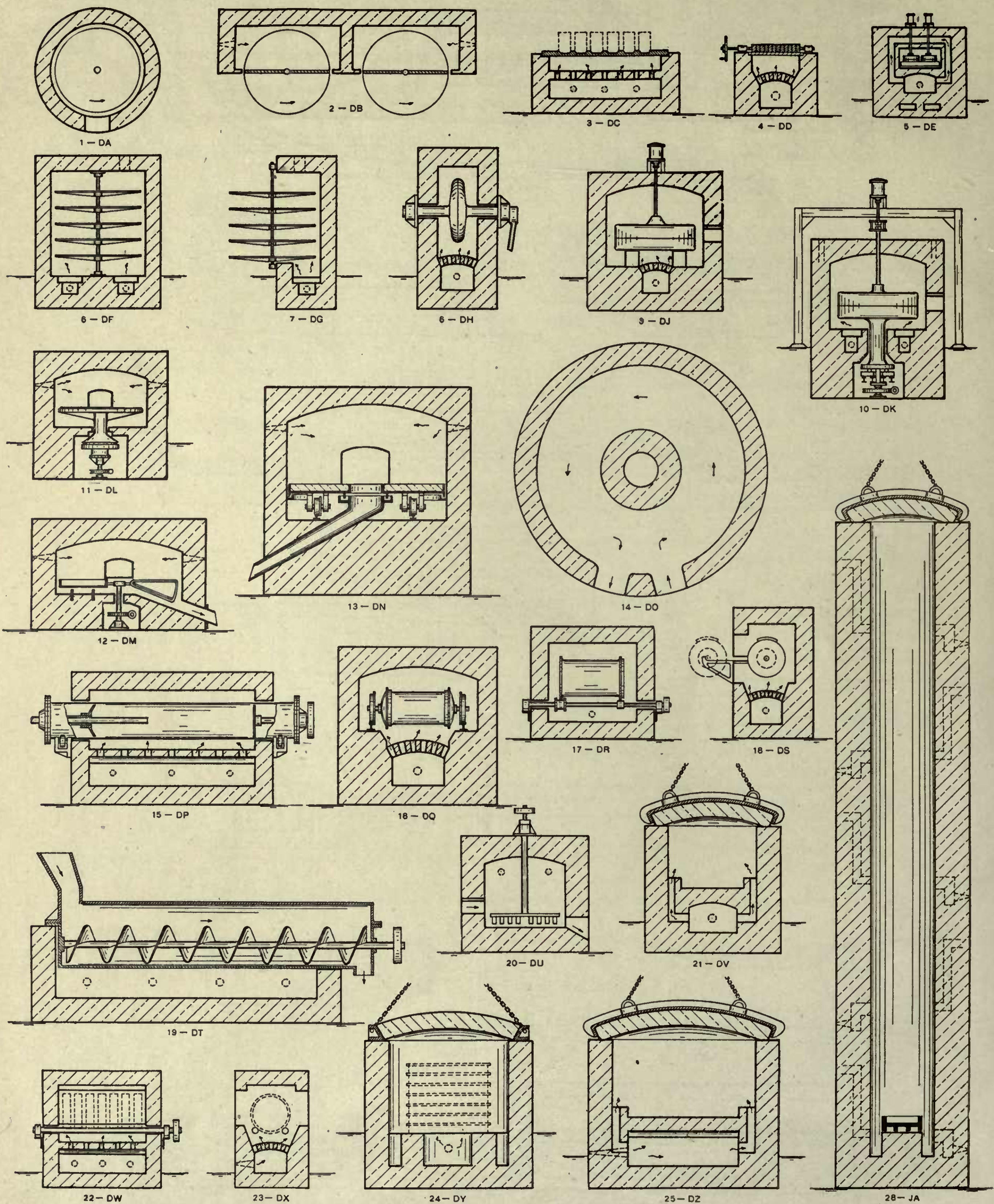
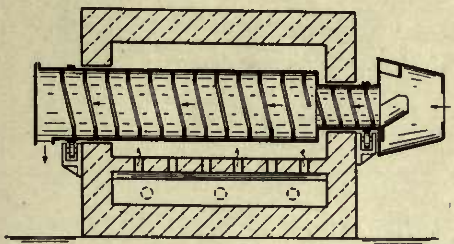


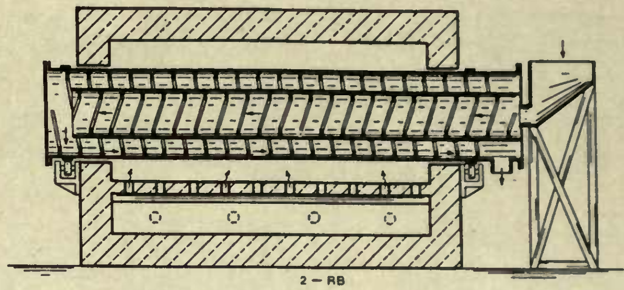
Fig. 15

ROTARY CYLINDRICAL FURNACES

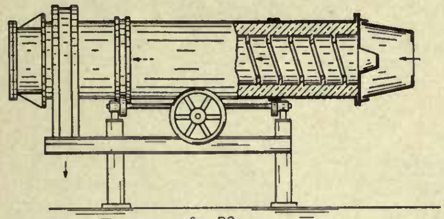
INTERNALLY AND EXTERNALLY FIRED TYPES FOR ANNEALING AND HEAT-TREATING BOLTS, RIVETS, FORGINGS, CUPS, HUBS AND OTHER MISCELLANEOUS MATERIAL – DRYING, OXIDIZING AND REDUCING METALLIC AND MINERAL POWDERS – HEAT-TREATING OPERATIONS IN SEQUENCE



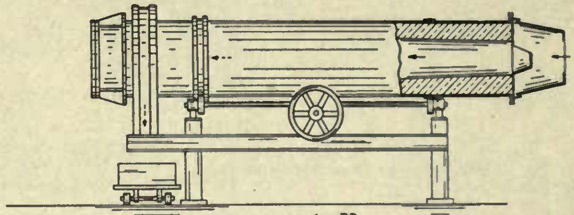
1 — RA



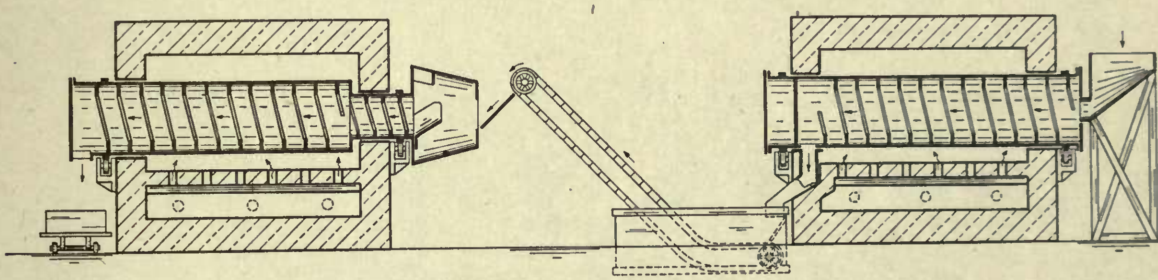
2 — RB



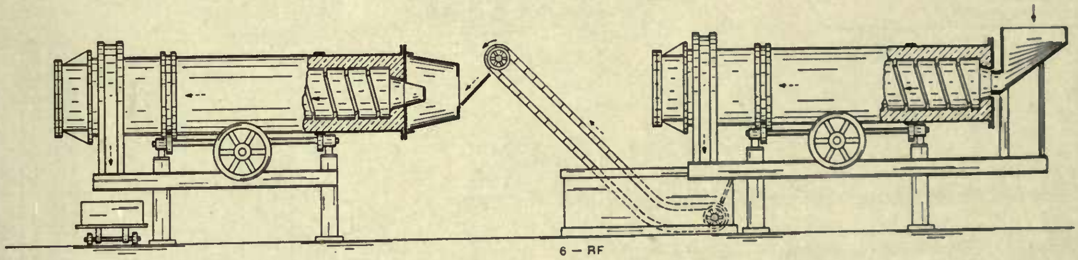
3 — RC



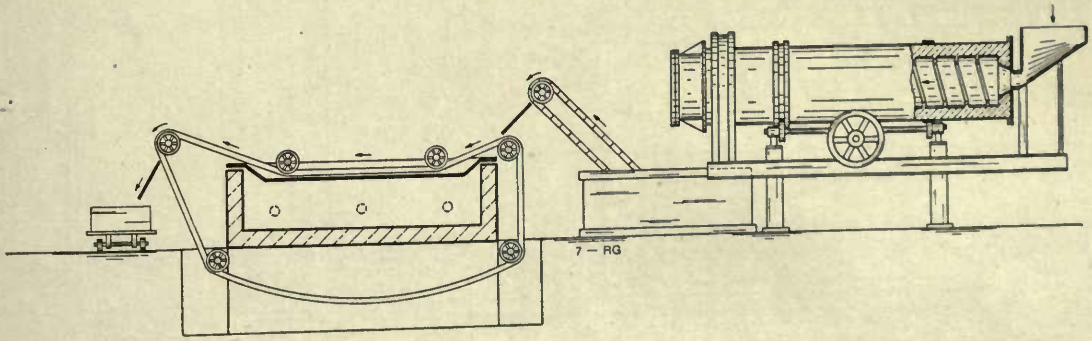
4 — RD



5 — RE



6 — RF



7 — RG

Fig. 16

AUTOMATIC HEAT-TREATING FURNACE ARRANGEMENTS

ROTARY CYLINDRICAL TYPE IN SERIES FOR A THREE-OPERATION HEAT-TREATMENT, WITH MECHANICAL TRANSFER – CARRY-THROUGH AND INSIDE DISCHARGE WALKING BEAM TYPES FOR ANNEALING AND HEAT-TREATING – FLOOR PLAN OF CONVEYOR FURNACES IN COMBINATION WITH FORMING MACHINE AND QUENCHING TANK

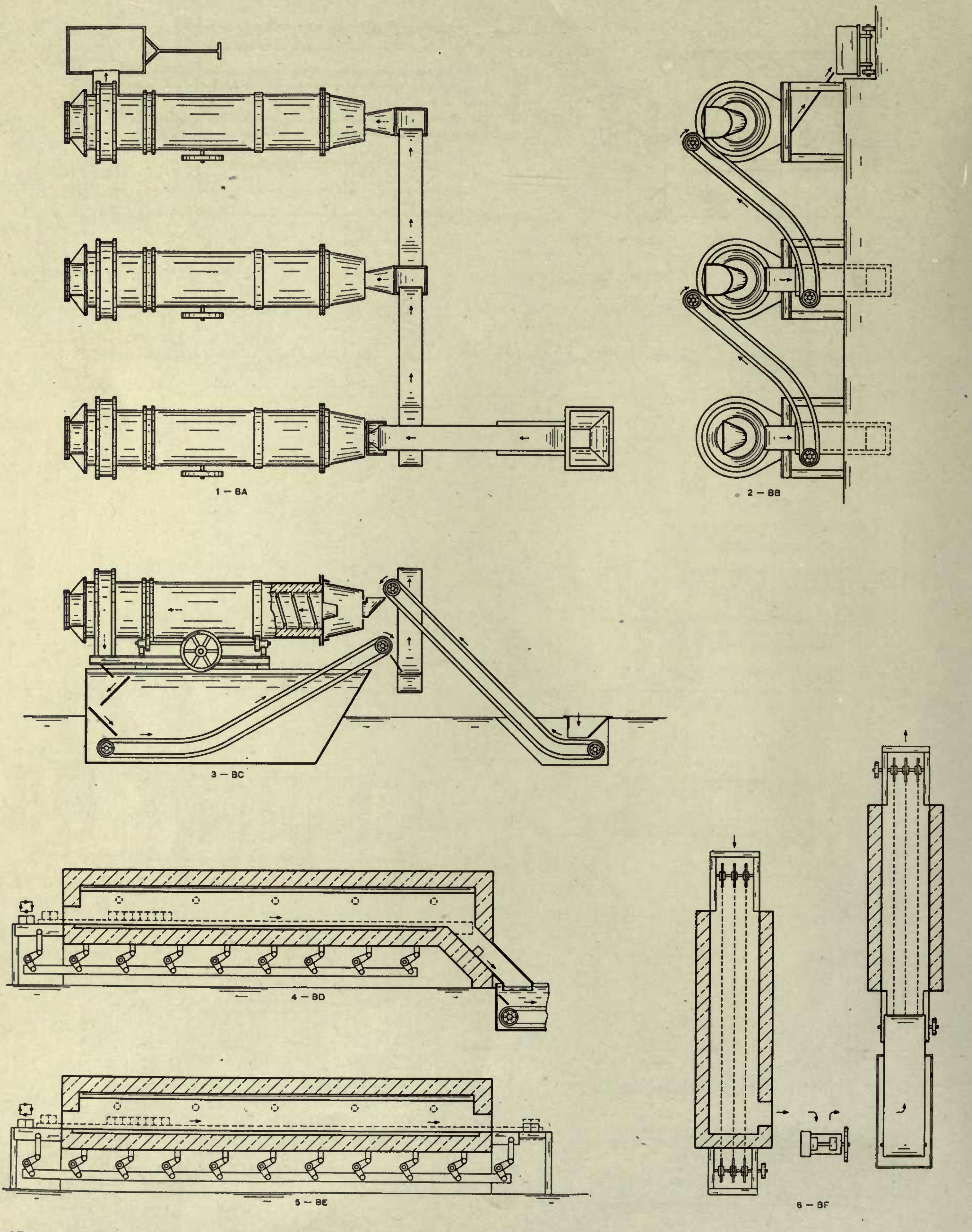


Fig. 17

MELTING FURNACES

SCRAP RECLAIMING – VITREOUS ENAMEL MELTING – PRECIOUS AND NON-FERROUS METAL MELTING IN STATIONARY AND TILTING CRUCIBLE AND REVERBERATORY TYPES

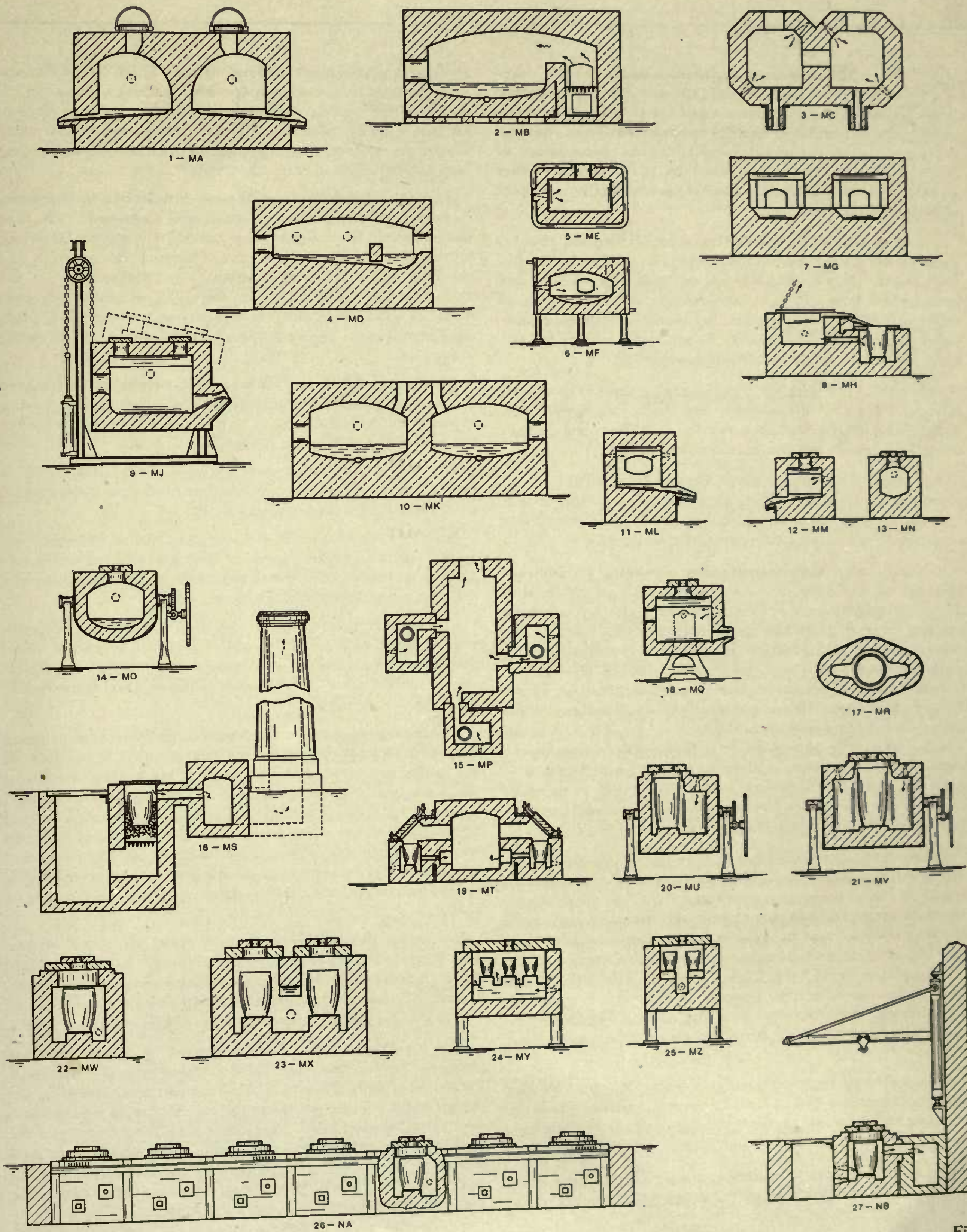


Fig.

Scope and Limitations of Regenerative Furnaces

THE **regenerative furnace** illustrates the necessity of considering the suitability of type and design of furnace and form of heat energy (combustible or electric) and **the relation of thermal conditions incident to the generation or utilization of heat in a furnace to other equally essential factors that influence the quality and cost of heat-treated products.**

Like the thermally efficient gas or oil engine, the regenerative furnace has its limitations as well as its field of usefulness. It is an efficient type of furnace for releasing and utilizing heat from fuel, and is particularly suitable for the use of fuels, such as producer gas, which, by reason of chemical composition and low calorific intensity, are not suited to high temperature heating requirements without regeneration.

The regenerative principle, by recovering a part of the sensible heat carried out of the heating chamber by the spent gases, and utilizing it to preheat the air or fuel, or both, permits a high ruling temperature and results in economy of fuel.

The regenerative furnace should be considered when the temperature and nature of the heating process, the size of the furnace, the cycle of operation or the plant conditions will not permit of a simpler or cheaper method of securing the result desired.

Regeneration, like recuperation, is really an indirect method of utilizing or recovering heat, and at times is limited to preheating the air alone, as certain fuels, such as natural gas and other hydrocarbon gases, cannot be preheated to the extent possible with producer gas. **When the temperature requirements and plant conditions permit the use of furnaces with more direct methods of utilization or recovery, the regenerative principle is unnecessary.** But where a high temperature is required, as for heavy forging, welding or melting operations, **it is frequently necessary to resort to regeneration** in order to establish a sufficient temperature differential, to increase the rate of heating, or **to make possible the attainment of the desired working temperature, regardless of the saving in fuel** or cost of furnace.

Considerable time is required to raise the temperature in the regenerative furnace from a comparatively cold condition to a relatively high working temperature. This is objectionable when the furnace is used only eight or ten hours per day, unless the heat is maintained between shifts to balance radiation and flue losses. Temperature requirements and the nature of the heating process or of the fuel may, however, make this furnace and practice desirable even under such intermittent operation. The objection does not hold when the furnace is operated continually at working temperature and capacity in two or more shifts.

Practically all regenerative furnaces are of the "batch" type and, therefore, limited in ability to continually maintain the chamber at full working capacity and at uniform temperature, due to the "batch" method of charging and discharging.

The requirements of temperature, output and the nature of a process, such as melting, may make this batch handling necessary. In other operations not confined to the "batch" type furnace, an increase in production requirements without a change in the nature of the heating process may suggest a different type of furnace, capable of showing equal fuel economy with added advantages in the method of applying and utilizing heat, handling material, reduction in floor space, etc.

Regeneration should not be considered when the furnaces required are comparatively small and scattered. The floor space required for a regenerative furnace is relatively large, due to the area of the regenerators, reversing valves, flues and chimney, which frequently occupy a greater space than the furnace itself. This, with the heavier foundations required, must be considered with the production requirements, plant conditions and the space available for the furnaces, machines and operatives.

There is a limit in the size of a regenerative furnace below which it is impracticable to go, because the possible economy in fuel is outweighed by other considerations related to the cost of installation and operation.

The regenerative furnaces of Rockwell design illustrated on page 27, all of which were built prior to 1900, compare favorably with the best present-day practice.

From the standpoint of fuel economy, these furnaces were entitled to consideration prior to 1900 just as they are today. Conditions limited their use at that time just as conditions, of a different nature, limit their use now.

The tendency to consider the regenerative or recuperative furnace as a possible solution of the so-called "fuel problem" should lead to consideration of conditions responsible for the limited use of such furnaces in the past and the extent of their use in the future.

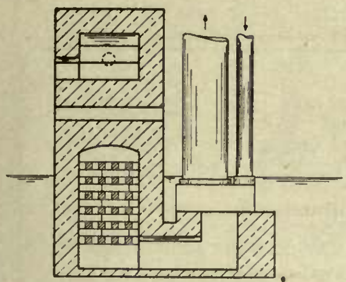
The relative cheapness in the past and flexibility of such highly concentrated fuels as natural gas and oil made it possible for the manufacturer to conduct many of his heating operations without regard to fuel conservation. As fuel was cheap and apparently not worth saving, the regenerative furnace did not often appeal to him. Production, rather than cost of fuel, was the order of the day. This, with relatively low labor cost and working conditions not now countenanced, have been responsible for the lack of progress that should have followed as a matter of course.

Changing conditions and the demand for better quality and decreased cost, coupled with relatively higher prices for material, fuel and labor, **will compel an increasing appreciation of all the factors that control the selection and use of furnaces and fuels** for the production of heat-treated products.

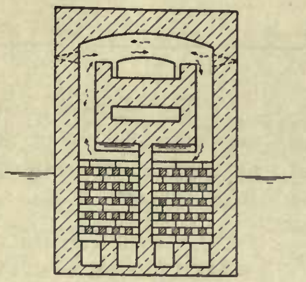
The question is not merely one of building a furnace properly, but of determining the proper type and design of furnace to be built, with due regard to its suitability to the nature of the heating operation, the manufacturing requirements and the plant conditions. This calls for a careful study of the problem as a whole, in order that none of **the essential factors affecting the quality of product and the cost of production** in the plant may be overlooked in an abstract consideration of the generation and utilization of heat in a furnace.

REGENERATIVE FURNACES

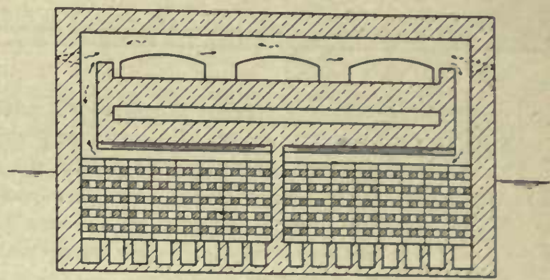
FORGING — WELDING — ROLLING — CRUCIBLE PIT MELTING



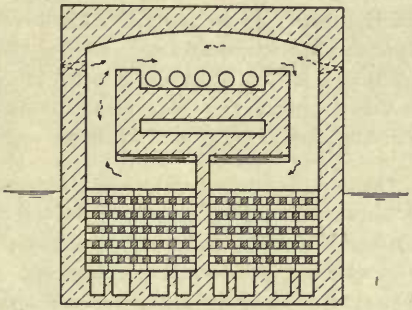
1 — ZA



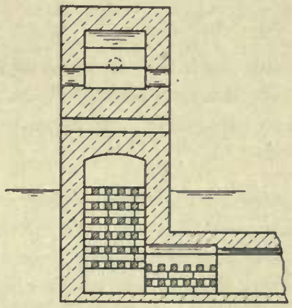
2 — ZB



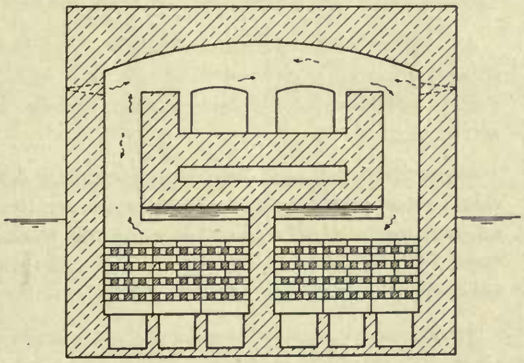
3 — ZC



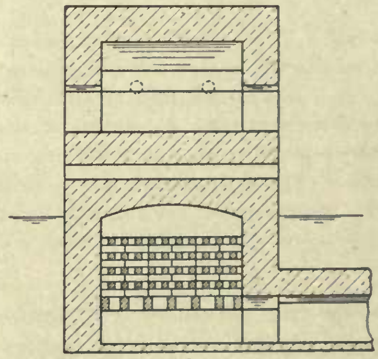
4 — ZD



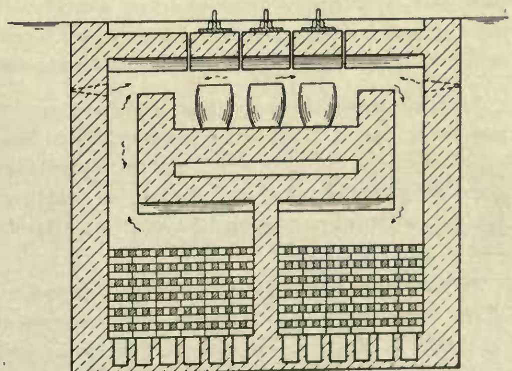
5 — ZE



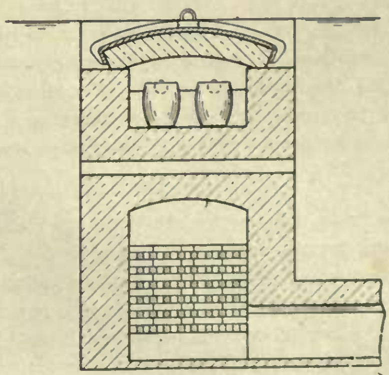
6 — ZF



7 — ZG



8 — ZH



9 — ZJ

Fig. 19

Relation of Type and Arrangement of Equipment to Cost of Production

ONE of the prime necessities when selecting industrial heating equipment is to provide means for such **heat application to the material as will produce the best quality of finished product.** It is equally necessary to provide equipment of such nature, extent and arrangement as will afford the **best means for handling as well as heating the material** in order to produce the greatest quantity at the lowest cost. And it is certainly advantageous to provide **means for the operatives to work efficiently and in reasonable comfort.**

All these considerations should contribute to the final result, so that the required quality and quantity of finished product may be secured with minimum labor, fuel, power, floor space, rejected material and overhead charges.

The advantages of adapting industrial heating equipment to the manufacturing requirements and plant conditions in each individual case are not always appreciated. Consideration only of strictly thermal features of the operation is often responsible for failure to effect **the economies** which, almost without exception, may be **brought about by intelligent selection, arrangement and operation of equipment properly adapted to the individual plant conditions.**

No two cases are alike. Two plants manufacturing the same product in the same quantity may require different heating equipment or different fuel, just as they may require different building construction or different methods of handling the material. Two separate departments of the same plant working on the same material may require different equipment, fuel or methods on account of different manufacturing requirements or other influences such as location, floor space, relation of these to each other, etc.

A different and better type of furnace, a different arrangement of furnaces or other equipment, method of handling, form of fuel or all together may so alter an overcrowded, uncomfortable heating department that it will turn out more and better product at less cost.

The furnace floor plans on page 29 (without reference to size of furnace or manner of heating) illustrate different arrangements of chambers and working openings, and suggest different types and designs of furnaces and various methods of charging and discharging in order to secure the greatest uniformity of product and rate of production.

"1-KA" may be a tool room forge with a chamber a few inches wide or a plate heating furnace fifteen or twenty feet wide. Or it may vary in length from a size required to heat a small tool up to one suitable for a steel shaft a hundred feet long. It may represent the chamber in a japanning oven maintaining heat at a few hundred degrees or a furnace for forging steel.

"25-KZ" similarly may vary in chamber size and temperature, with means for moving the material through the chamber continuously or intermittently, or for charging and discharging at either or both ends.

Either of these may be built in double-chamber form (7-KG or 29-LD) with similar variations in size or temperature, and various methods of handling material and producing and applying heat.

Many such combinations may be provided to facilitate the proper heating and handling of the material. Other combinations may be warranted by the necessity for improvement in working conditions, to employ the floor space to better advantage, or to effect the general all-around economy that frequently results from discarding comparatively small and inefficient furnaces in favor of the larger and heavier units.

The type, design, size and number of furnaces, with reference to the form and calorific intensity of the fuel or heat energy, and the methods of handling and routing material must be determined with reference to the methods of heat application, manufacturing requirements and plant conditions. **The furnace units should be as few as possible to secure the desired output with continuity of operation.** Each should be properly designed and proportioned so that it will contribute its share of properly heated product with economy of fuel, labor and floor space.

A number of small furnaces should not be considered when fewer larger units may be employed, because of the relative reduction in floor space, radiating surface, fuel consumption, time and labor.

Manufacturing requirements for quality product at low cost under conditions of quantity production frequently suggest mechanical means for handling to such an extent that the furnace is in reality an automatic heating machine.

Such automatic methods represent ideal practice and should be chosen wherever the conditions permit. The field of usefulness of such automatic methods, however, is limited by the quantity or rate of flow of the material to be heat-treated, and by variations in size, shape or composition of the individual pieces or batches, and by other conditions that do not permit of strictly continuous operation on a comparatively large scale.

To heat correctly is the first consideration. Whatever the manner of heat application or method of handling material, it must always be borne in mind that the **fundamental factors governing uniformity of heating or cooling cannot be ignored without corresponding sacrifice** in quality of product and ultimate cost.

To heat economically it is necessary to consider the influence of the type, design, size, number and arrangement of furnaces on the items of labor, fuel, output, floor space, and investment, and other items included in the actual cost of production.

ARRANGEMENTS OF FURNACE CHAMBERS AND WORKING OPENINGS

SOME OF THE POSSIBLE ARRANGEMENTS OF FURNACE CHAMBERS AND WORKING OPENINGS AVAILABLE FOR MEETING INDIVIDUAL REQUIREMENTS AS TO MATERIAL TO BE HEATED, CHARACTER OF OPERATION AND PLANT CONDITIONS

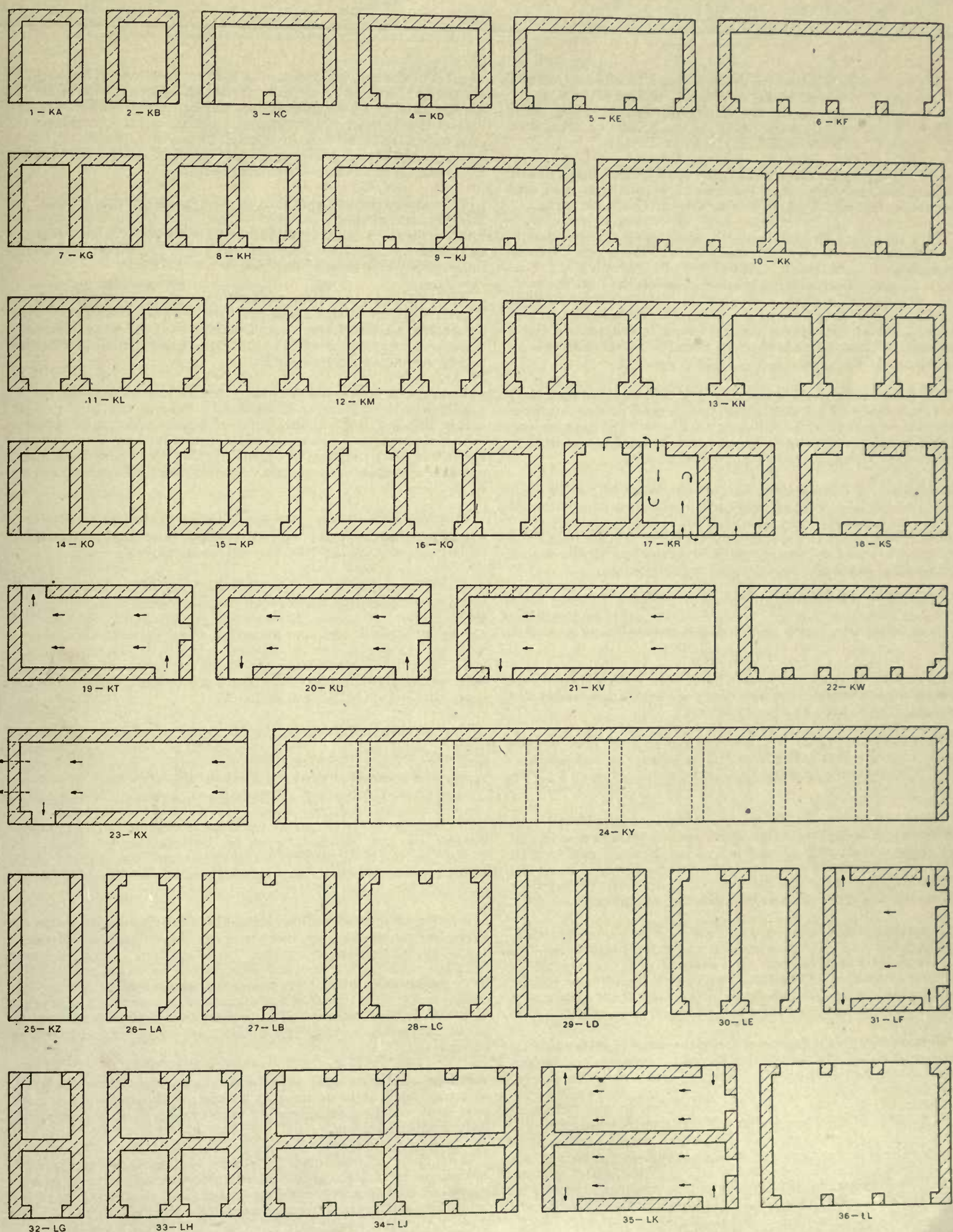


Fig. 20

W. S. ROCKWELL CO. INDUSTRIAL FURNACES ESTABLISHED 1888 NEW YORK

Relation of Price of Fuel to Cost of Production

THE **relation of price of fuel** to ultimate cost of production in industrial heating is, in many respects, similar to that prevailing under other conditions involving the use of fuel or heat, such as illumination or transportation.

The character and cost of the final result are determined by a combination of apparatus, fuel and operative, and not by any one or two of these factors.

The cost of fuel, which is based upon the price and quantity consumed, is but one item in the ultimate cost of production. The fuel consumption is governed by the design of the furnace and the manner in which the heat is generated, applied and utilized. The average manufacturer does not control the price of fuel, but to a great extent **he can control the cost of his heating operations by using furnaces and fuels adapted to his manufacturing requirements and plant conditions.**

Too great emphasis is usually placed on the heat unit (B. t. u.) cost of fuel and upon the details of combustion and heat release; and too little attention is given to the economy attainable under better methods of heat application and utilization possible with apparatus of improved design.

The practice of selecting fuel on the basis of "heat unit cost," or of selecting apparatus to use any one form of fuel on the basis of "heat balance," or "fuel consumption," without considering the mechanical form and suitability of the apparatus, or the intelligence and skill of the operatives, is just as illogical in industrial heating as in transportation.

Many absurd comparisons are made between different fuels merely on their heat unit content, without regard to physical and chemical form, which very largely determine their field of usefulness.

Price, on the basis of heat unit content, must be considered together with the form of fuel and apparatus, and the suitability of both to the conditions.

The economic value due to "form" of fuel and equipment, suggests consideration of "form value" in the selection of fuels and furnaces or other apparatus dependent upon heat for operation.

"**Form value**" is a term denoting the intangible value due to **physical condition** or **chemical association** of a source of heat energy (combustible, electrical or mechanical) and method (apparatus and operation) of transformation into useful service. It is not measured by the thermal (B. t. u.) value or the price of fuel, nor the type, price or heat balance of a furnace.

Innumerable instances in the fields of power production, transportation, and illumination indicate that "**form value**" **is of greater importance than thermal value** in the selection of fuel and apparatus. Otherwise no other form of heat energy could compete with bituminous coal, and the chief elements of progress in each field thus far attained would be nullified.

"Form value" is a factor of fundamental significance in the problem of selecting fuels and furnaces or other apparatus dependent upon heat for operation. Accordingly, an adequate survey of the problem should include specific consideration of the "form value," in addition to the "thermal value," price of fuel, "heat balance," and cost of apparatus.

Such survey is necessary for an unbiased consideration of the problem as a whole and a proper appraisal of the actual requirements. **Individual conditions and the economic value of the ultimate result** must decide the conflicting claims of advocates of the arc, induction or resistance methods of heating by electricity; combustion experts; those urging the merits of different forms of gas generated in isolated or central station plants; fuel oil or powdered coal enthusiasts; mechanical stoker adherents, etc., or those interested in special forms of furnaces or other apparatus without reference to the form of fuel or electricity to be employed in connection with them.

The approximate relation of the heat energy in fuel to the results accomplished by its use, and the possibilities for improvement in application and utilization of such heat energy, are illustrated by the diagrams on page 31, which are fairly representative of present-day practice.

The indirect relation of the cost of fuel and the more **direct relation of the combination of equipment, fuel and operative** to the character and total cost of the service or product is even more pronounced in industrial heating than in the more highly developed field of power.

Inadequate appreciation of the great variety of manufacturing conditions; the difficulty of definitely valuing the quality and cost of finished product; and the too frequent practice of appraising the operation by thermal standards only, lead to neglect of the principles governing the production of heat-treated products and the selection and operation of apparatus as a proper means to that end.

It is apparent from practice that unless other conditions are equal, the cost of fuel or so-called "thermal efficiency" of the apparatus are not the determinative factors.

The common hot-air engine extensively used in isolated country districts for pumping water, and for other operations requiring a small amount of power, is relatively inefficient in utilizing fuel energy compared with the Diesel or other internal combustion engines. Under certain conditions, however, it has some operating advantages in permitting the use of comparatively cheap fuel and requiring minimum attention, the economic value of which more than offset the loss in fuel.

The simply constructed and operated foundry cupola for melting grey iron is generally considered an example of thermal inefficiency compared with the modern regenerative open hearth furnace for melting steel. Although the two should not be compared on the basis of "heat balance," because of the difference in construction, operation and purpose, it is interesting to note that the cupola is the more efficient of the two **in heat application to the product and in utilization of heat.** If it were operated continuously and the waste heat utilized as in blast furnace practice, the comparison would be even more striking.

Similar comparisons, illustrating **the economic value due to form of apparatus or heat energy** regardless of "thermal efficiency," represented by the "heat balance," may be made between steam, electric or gasoline-driven cars moving on rails and automobile trucks or passenger automobiles moving on roads; and internal combustion engines of two or four cycles with 1, 2, 4, 6, 8, 12 or more cylinders to meet the varying requirements of automobiles, watercraft, aircraft, or small isolated power plants.

While the heat unit standard is a gauge of the thermal value of fuel, it is not a real gauge of its economic value, nor is the "heat balance" a real gauge of the economic value of apparatus.

Each form of fuel, electricity and appliance has its field of usefulness as well as its limitations. Proper selection of equipment and fuel to suit conditions necessitates consideration of all factors governing the accomplishment of a specific result.

HEAT DISTRIBUTION IN ENERGY CONVERSION APPARATUS

ECONOMIC VALUE OF BY-PRODUCTS, POSSIBLE HEAT RECOVERY AND THE EFFECT OF OPERATING CONDITIONS NOT CONSIDERED

D-25
2521

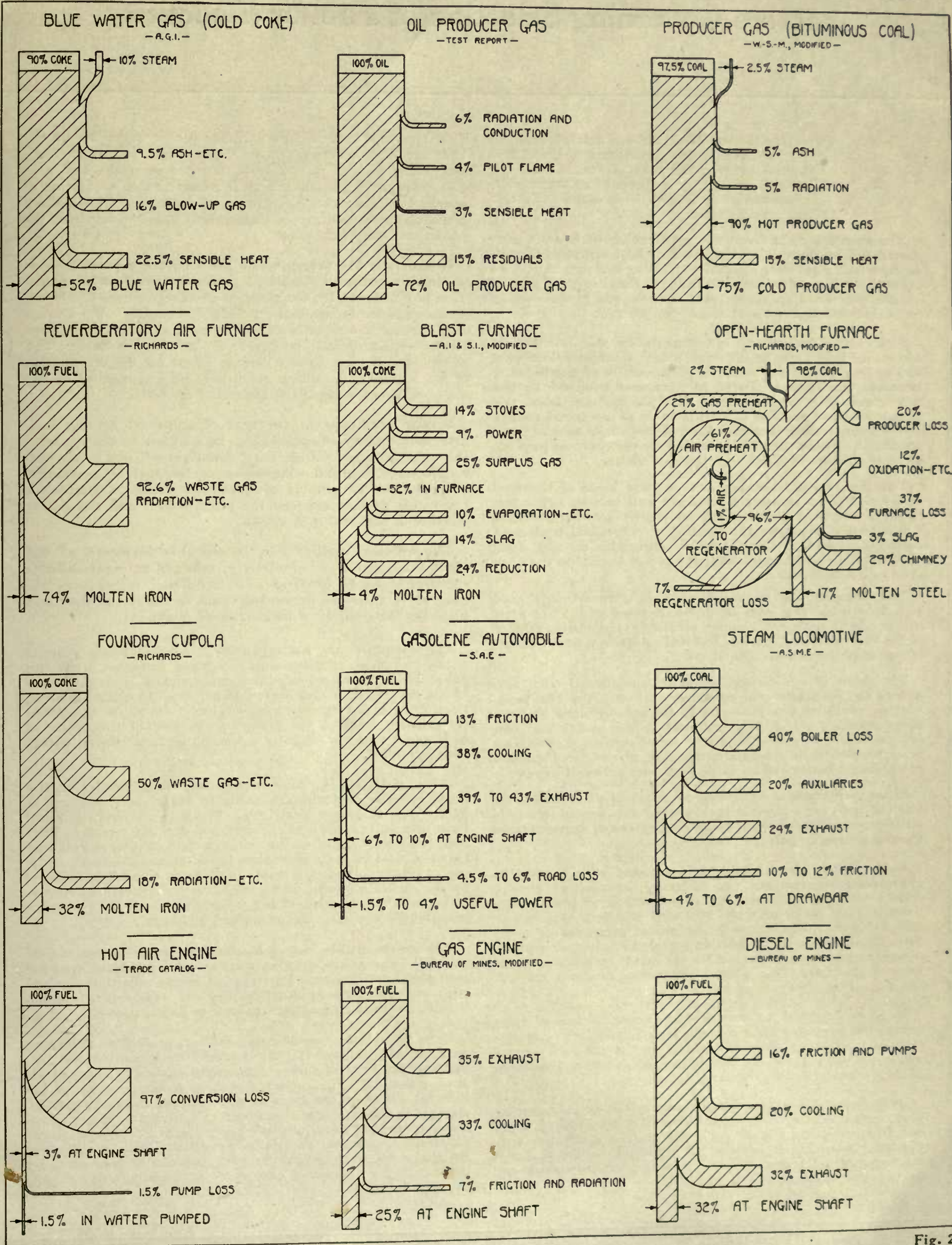


Fig. 21

Factors Governing Selection of Fuel or Electricity

THE selection of fuel for industrial heating should be based upon appreciation of the radical difference between the price of fuel, on the one hand, and the quality and cost of product resulting from the generation, application and utilization of heat, on the other.

The result sought from the application of heat is produced not by fuel or heat alone, but by a combination of equipment, fuel and operative. These elements should be selected with regard to their suitability to the conditions governing the conduct of the operation as a whole, and to their ability to produce the desired result at a reasonable cost.

In industrial heating, as in transportation and illumination, a complex field must be surveyed before a proper selection of fuel and equipment can be made. **The nature of the heating process, the type and size of furnaces adapted to the manufacturing requirements, the plant conditions, the personnel, and price of available fuels or electrical energy are the controlling factors.** Each of these must be considered together with other essentials outlined by the chart on page 33, any one of which may influence the final choice.

The practice of selecting fuel on the basis of thermal value and price is both inaccurate and misleading unless at the same time proper consideration is given to other essentials which largely determine the suitability of fuel and equipment regardless of price or thermal value. Otherwise, no other form of fuel could compete with bituminous coal burned in the open grate or blacksmith fire.

The price of fuel may influence but it certainly does not determine the cost of finished product. Price must be considered with the amount consumed and the suitability of the "form value," both of fuel and equipment, to the nature of the heating operation as a whole.

The form of equipment must be considered with reference to the manner of applying and utilizing the heat, and of handling the material to be heat-treated, because these essentials are as directly linked to the quality and cost of finished product as are the price of fuel or method of generating heat, whether it be through combustion or the arc, induction or resistance methods of releasing heat from electrical energy.

Whenever there is a difference in physical or chemical form of fuel, or in mechanical form of equipment, there is a difference in economic value regardless of comparative thermal value or price.

Fuels of the same physical form may vary greatly in chemical composition. A difference in ash, sulphur or moisture content of coals, or in percentage of inerts, combustibles, or combination of the same chemical elements in different gases, may influence the choice regardless of price. The difference between the arc, induction and resistance methods of releasing heat may influence the choice of equipment and the form of electricity, i. e., whether alternating or direct current, and the voltage, phase or cycle.

It is as illogical to compare different forms of heat energy with regard to a certain result, as it is to compare electricity with any one form of fuel on the basis of thermal value, **unless proper consideration is given to the form of equipment adapted to each.**

In industrial heating, as in illumination or transportation, much of the advantage frequently credited to some one form of energy is actually due to the appliance employed in connection with it. A different design of appliance or method of operating may reverse conclusions based on thermal value or price.

The relative cost of kerosene, city gas or electricity on the heat unit basis is determined by the price per gallon, per thousand cubic feet, or per kilowatt hour, respectively, but such comparisons do not indicate their relative value as sources of energy for illumination. The price and form of energy is usually considered with the type of lamp, which largely determines the nature and cost of the result.

Frequently the "form value" of a suitable combination of equipment and fuel will prevail regardless of price. This is illustrated by the practice of using comparatively expensive gas for intermittent cooking operations in the kitchen in preference to comparatively cheap coal, which under different service requirements is preferable for heating the house. The advantages of incandescent electric lamps for the illumination of the interior of a railway coach may be accompanied by the use of oil lamps as signals at the end of the train.

Similar conditions in the field of industrial heating indicate the necessity of considering, in addition to the apparent value due to price of fuel, the **"form value"** due to physical condition or chemical composition of the fuel or mechanical characteristics of suitable equipment, in order to establish a reasonable balance between the price of fuel and the nature and cost of the heating operation.

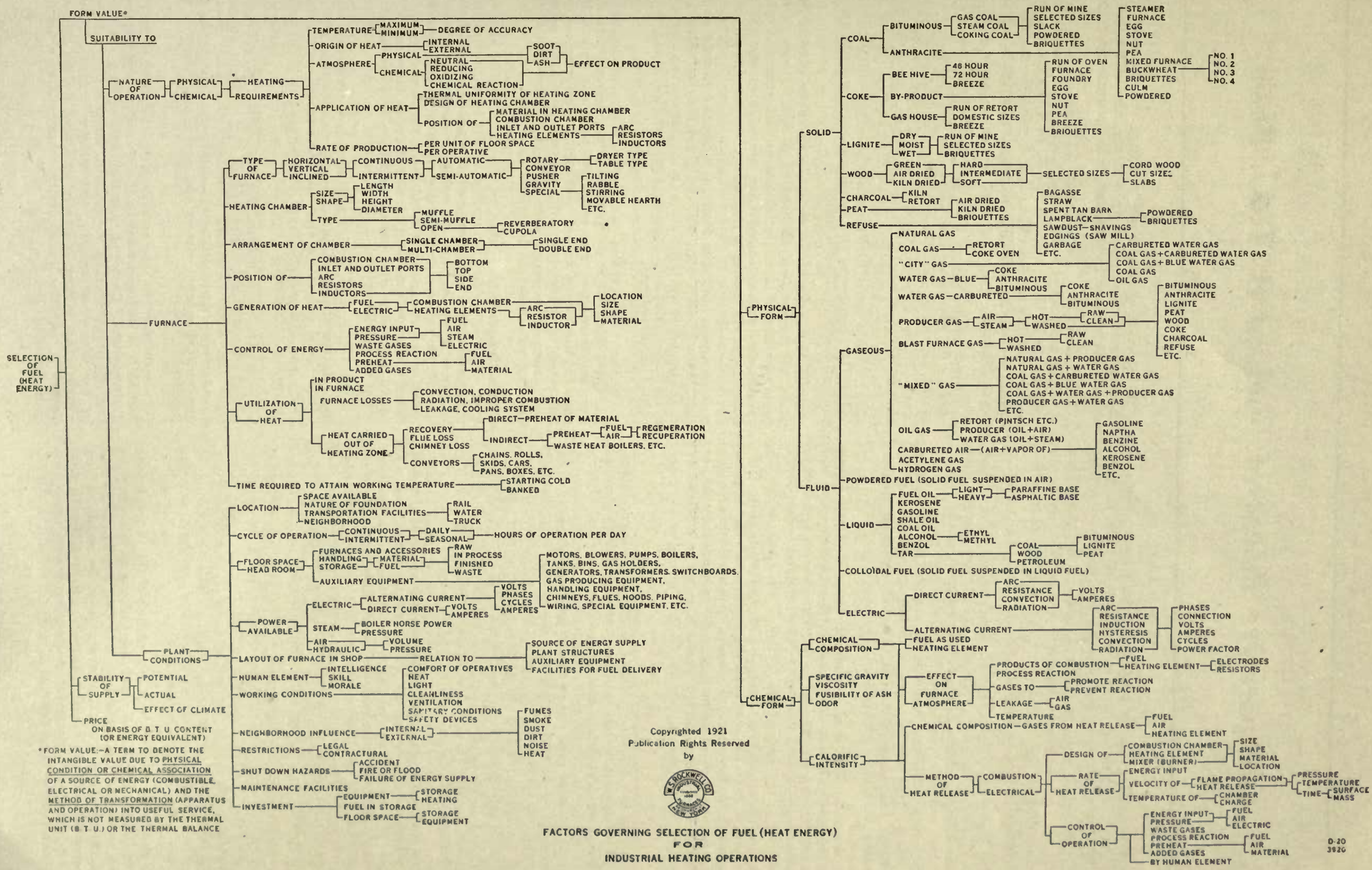
The efficient utilization, in suitable furnaces, of the right form of fuel or electricity, selected to meet definite requirements of heating and handling, rather than the price alone, **must be depended upon to lower the cost and improve the quality of heat-treated products.**

The nature of the heating process, manufacturing requirements and plant conditions may in many instances make city gas at $1 per thousand cubic feet economically preferable to oil at one cent per gallon, or coal at $1 per ton. In other instances, electricity at a very much higher price, based on equivalent energy cost, is given the preference because of the operating advantages made possible by a specific form of electric energy and appliance.

A fuel such as bituminous coal may be attractive on the basis of price but objectionable in form, or vice versa, as in the case of gas or electricity. Gases of the same physical form may vary greatly in chemical composition, which in itself may limit the field of usefulness regardless of price. **Suitable furnace design may overcome these objections.** Thus the use of bituminous coal is made possible in enameling furnaces by the use of a muffle, which might be unnecessary in electric furnaces in which gases, if any, originating from the resistance material did not affect the product to be heated.

The innumerable factors controlling the selection of fuel and the generation, application and utilization of heat for industrial or domestic purposes, denotes a field of usefulness, in suitable apparatus, for all varieties of solid, liquid, gaseous and electrical fuel or heat energy.

Extension of the use of any one form of fuel or electricity automatically follows the development of apparatus for converting that form of energy into useful service in heat, power or illumination. The apparent relative economic value of the different forms on the basis of price, at the moment, may be changed in the future, as it has been in the past, by the development of **better methods of heat application and more efficient apparatus to make possible either a different result or to accomplish the same result at less cost,** by decreasing the amount of energy required without any change in the price.



FACTORS GOVERNING SELECTION OF FUEL (HEAT ENERGY)
FOR
INDUSTRIAL HEATING OPERATIONS

Fig. 22

Comparative Prices of Fuel on B. T. U. Basis

THE chart on page 35 affords a ready means of comparing fuels on the basis of their B. t. u. cost—by direct comparison of the price of one fuel with the price of another; by comparison of the relative costs per million B. t. u., or, on an assumed cost per million B. t. u., reading directly the "permissible" prices for various fuels.

The horizontal lines represent prices for fuels; the vertical lines, costs per million B. t. u. of heat energy; the diagonal lines are the plotted heat unit values of fuels. The chart is read by converting the price of a given fuel (horizontal line), at its intersection with the diagonal line of the heat unit value of the fuel in question, to the vertical intersecting line which, read at the bottom of the chart, indicates the cost per million B. t. u., or vice versa.

To illustrate: For a comparison of 12,000 B. t. u. coal at $5.00 per ton with fuel oil. Reading from the left scale, the horizontal line from $5.00 per ton is followed to its intersection with the diagonal value line for 12,000 B. t. u. coal, then vertically down to the scale at the bottom of the chart, which indicates a cost of approximately 21c per million B. t. u. The same vertical line is followed to its intersection with the diagonal value line for fuel oil, then horizontally to the scale on the right of the chart, which indicates a price of approximately 3c per gallon, at which such fuel oil would have to be procured to equal on a heat unit cost basis 12,000 B. t. u. coal at $5.00 per ton.

Reversing this process, if fuel oil should cost 8c per gallon, this horizontal line carried to its intersection with the fuel oil diagonal, then down to the bottom, indicates a cost of approximately 56c per million B. t. u. This same vertical line carried to its intersection with the 12,000 B. t. u. coal diagonal, then horizontally to the left, indicates a comparative price for coal of $13.50 per ton. Direct comparisons are thus available between the coal and fuel oil prices; indicating that fuel oil would have to be available at 3c per gallon to equal in heat unit cost 12,000 B. t. u. coal at $5.00 per ton; and that if fuel oil cost 8c per gallon, 12,000 B. t. u. coal would be no higher in B. t. u. cost at $13.50 per ton.

This method of comparison takes into account the cost per million B. t. u. merely as an intermediate step. If desired, fuel prices may be compared directly. For example, following along the horizontal line of $5.00 per ton coal to its intersection with the diagonal 12,000 B. t. u. coal value line, then vertically down to the intersecting diagonal line for fuel oil, then horizontally to the right, reading directly the comparative price of 3c per gallon for fuel oil.

At an assumed cost per million B. t. u., the "permissible" prices for the various fuels to be considered will be found by following the vertical "cost per million B. t. u." line to its intersection with each of the fuels in question, then to the right or left respectively to read the "cents per gallon" for a liquid fuel, the "dollars per ton" for a solid fuel, or the "cents per thousand cubic feet" for a gaseous fuel.

In the cases of acetylene gas and electricity, the prices are read to the left and right respectively of the chart as cents per hundred cubic feet and per Kw.h. The vertical intersecting lines, however, must be read at the extreme bottom of the chart as dollars per million B. t. u. and transposed accordingly for comparison with the other fuels which are rated at cents per million B. t. u.

The chart "Industrial Fuels" on page 44 furnishes a direct B. t. u. cost comparison of the ordinary industrial fuels based on assumed prices which approximate the present-day market.

These charts have been prepared to facilitate a comparison of the B. t. u. cost of fuels, but in making such comparisons it must always be borne in mind that **B. t. u. costs are but one factor,** and in most cases the minor factor, affecting the total cost of any heating operation or the manufacture of any heat-treated product.

If mass generation of heat is considered without reference to its nature or use, then the B. t. u. cost of fuel would be the factor determining the choice. In practically all cases, however, the combustion of fuel—the generation of heat—is a preliminary to the application and utilization of heat in the accomplishment of a required result, and in every instance **there must first be considered the suitability of a fuel to the nature of the operation, equipment, and the general operating conditions.**

Much the same situation exists as in the case of foods, which are frequently considered as a form of fuel. Certain foods may be low priced in relation to their potential value in calories, and yet not suitable for use under every condition. Baked beans, for example, represent a low-priced food, and yet for the convalescent requiring a large amount of nourishment, such relatively high cost foods of different character as milk, eggs, animal jellies, etc., may be given the preference. The choice should be based not alone on the relative value in calories of such foods, but with regard to their **suitability to the individual requirements.**

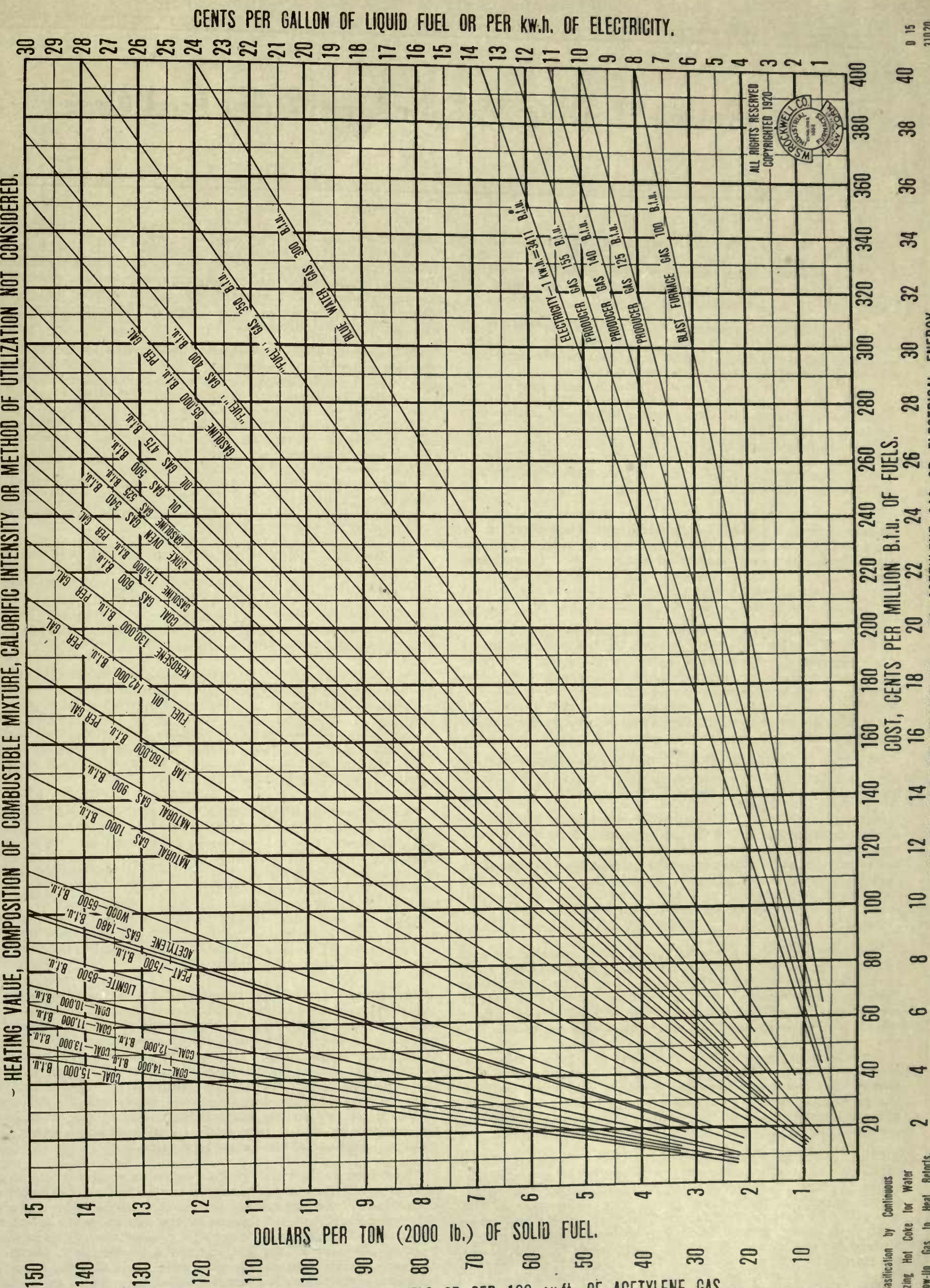
The term **"form value"** is suggested to give expression to the intangible value due to difference in physical characteristics and chemical association that exists between the various fuels; and it is the **"form value"**—in addition to price—of a fuel, influenced, of course, by the design and method of operating the equipment employed with it, that largely determines its economic value and field of usefulness.

It is the advantages due to "form value" of electricity with suitable appliances which, under certain conditions, suggests its use for illumination when gas or oil might be cheaper on a B. t. u. basis. Similar conditions may suggest the use of gas with the modern gas range for cooking in preference to coal, wood or oil at a lower B. t. u. price. Different conditions may warrant the choice of lower-priced fuels which, with suitable apparatus, may meet the operating requirements at reasonable cost.

With fuel, as with food, **the choice is determined not by the relative heat unit cost, but by consideration of price with "form value" of the fuel and equipment adapted to it, and the suitability of the combination to definite operating conditions.**

A comparison of fuels on the basis of B. t. u. value is not a test of economic value unless the fuels so compared have the same physical characteristics and chemical association and are utilized in appliances having the same mechanical characteristics and operated under the same conditions.

Price of fuel is but one item in the cost of heating, just as it is but one item in the cost of transportation or illumination. Operating cost includes not only the price of fuel, but also the quantity consumed, which is largely governed by the manner of applying and utilizing the heat in useful service. This in turn is greatly influenced by the design and method of operating the appliance, whether it be a furnace or a motor truck.



"Fuel" Gas: Gasification by Continuous Process Utilizing Hot Coke for Water Gas and Blow-Up Gas to Heat Retorts.

Comparative Heating Value of Industrial Fuel Gases

THE relative value of gases for industrial or domestic heating or power service is not definitely determined by the customary method of comparison on the basis of heat units (B. t. u.) per cubic foot.

It is a common belief that the suitability of a gas as a source of heat or power is determined by its B. t. u. value and price, and that gases higher in B. t. u. per cubic foot are the more desirable; but this is far from true.

The heat unit content of a gas is not a true indication of its heating value in an economic sense. In addition to the B. t. u. value there must be considered the chemical composition of the gas and of the mixture of gas and air supplied for combustion, and also the influence of the design of furnace or other appliance employed for the generation, application and utilization of the heat.

The chemical composition of a gas fixes the volume of air required for combustion, and the mixture so formed, from which the heat is released, has a B. t. u. value per unit of volume much less than that of the original gas itself. The quantity of air required for combustion of the various gases fluctuates greatly, being more for the richer gases and in general less with the decrease in B. t. u. value.

The heat unit value of the usual industrial gases may vary from 100 to 1500 B. t. u. per cubic foot; the theoretical quantity of air required for combustion may vary from one to twelve cubic feet per cubic foot of gas; the B. t. u. value of the combustible mixtures of these same gases, with the theoretical quantity of air required for combustion, may vary from 50 to 115 B. t. u. per cubic foot, or less with an increase in the relative quantity of air supplied. See chart page 37.

The B. t. u. value of a gas or its combustible mixture does not indicate the temperature obtainable by combustion or determine its field of usefulness.

Natural gas at 900 B. t. u., while apparently three times as rich as water gas at 300 B. t. u. per cubic foot, has a lower flame temperature and rate of flame propagation. Natural gas would not be as suitable as water gas for high temperature blow-pipe operations, such as welding. On the other hand, natural gas is preferable to water gas in internal combustion engines, in which the air and gas are mixed under heavy compression.

Producer gas, in its washed state, while suitable for gas engines, is not as well suited as water gas for high temperature operations, such as forging or welding, yet with regenerative furnaces it is extensively used for melting steel. **The design and operation of the furnace favor a field of usefulness which is not disclosed by an analysis of the gas itself.**

Both these gases and the air required for their combustion may be preheated to a high temperature in regenerative furnaces. If natural gas were employed in the same furnaces, the preheating would be limited to the air alone, because the natural gas, by reason of its chemical composition, would dissociate in the regenerative chambers at high temperatures.

Many examples from every-day practice with various forms of fuel could be given to illustrate the point not generally appreciated, that **the difference in composition or "chemical form value" of industrial gases, the influence of the quantity of air supplied for combustion, and the design of the appliance, denote fields of usefulness and limitations which are not revealed by the customary B. t. u. comparison.**

The distribution of natural gas is frequently affected in cold weather by the formation of solids in the pipe lines. The distribution of carbureted water gas under similar conditions frequently results in the deposition of oil in the pipe lines resulting from condensation of certain hydrocarbons peculiar to this gas. Producer gas, while relatively cheap and less susceptible to such conditions in transportation, is not suitable for general distribution by reason of its low heating value and unusually high percentage of incombustibles.

By reason of their composition, gases such as acetylene or blue water gas have a more or less well defined field of usefulness, which makes them unsuited for the average domestic or industrial heating requirements.

"City gas" is well adapted to the average industrial and domestic heating operations. As a domestic fuel it has become almost indispensable, particularly in congested districts. An efficient extension of its use is highly desirable for the influence it will exert on conditions of living and manufacturing and in conservation of fuel resources. Its field of usefulness in industrial heating, at present, is narrowed by relatively high price and comparatively inefficient appliances.

The prevailing high price of "city gas" is very largely due to existing costly and wasteful methods employed in its manufacture and distribution—an inheritance from the days when gas was used primarily for illumination. This results either in **a needless production of "domestic coke" or the use of oil and anthracite coal, which could be well diverted to more essential purposes.**

The improvement of electric appliances, resulting in an extension of the use of electricity for many industrial heating operations which could be efficiently conducted with gas, is gradually developing an appreciation of the fact that **the customary methods of gas manufacture and utilization must be superseded by others better adapted to present-day conditions if the gas industry is to survive and render its full measure of service.**

The need may be supplied by a **"fuel gas"** generated through complete gasification of bituminous coal, under standards which will **eliminate the oil or anthracite coal or "domestic coke" to maintain obsolete candle-power requirements or unnecessarily high heat-unit value.** The heating value could be lowered to approximately 400 B. t. u., which, with suitable chemical composition to meet requirements of flame temperature and odor, would be well suited to present-day domestic and industrial conditions; for, as indicated by the chart on page 37, it would be substantially equal to the present-day "city gas" in heating value.

Low-priced gas of the proper heat value and chemical composition is not in itself sufficient, because the cost and nature of service to the consumer are determined not by price alone, but by the quantity consumed and the design of heating appliances. The appalling waste of natural gas in the operation of industrial furnaces, which generally lack the essentials of air control and dampers provided with the common coal kitchen range or house heater, and the influence of excess air in lowering the heating value of gases, indicate **the influence of furnace design and operation upon the quality and cost of the heating service.**

Electricity, at a much higher price on equivalent energy basis, has outdistanced gas for many industrial heating operations; not always by reason of inherent advantage in electricity itself, but **by reason of its use in more efficient furnaces or other appliances.** A comparison of the relative thermal efficiency of the average gas appliance with electrical appliances offered for the same purpose, indicates the need for improvement and **the influence of the design and operation of equipment upon the cost of product or heating service, of which the price of fuel is but one factor.**

COMPARISON OF INDUSTRIAL GASES

APPROXIMATE COMPOSITION—ENERGY CONTENT AND CALORIFIC INTENSITY OF GASES AND COMBUSTIBLE MIXTURES

FURNACE DESIGN AND OPERATION NOT CONSIDERED

D-17
2920

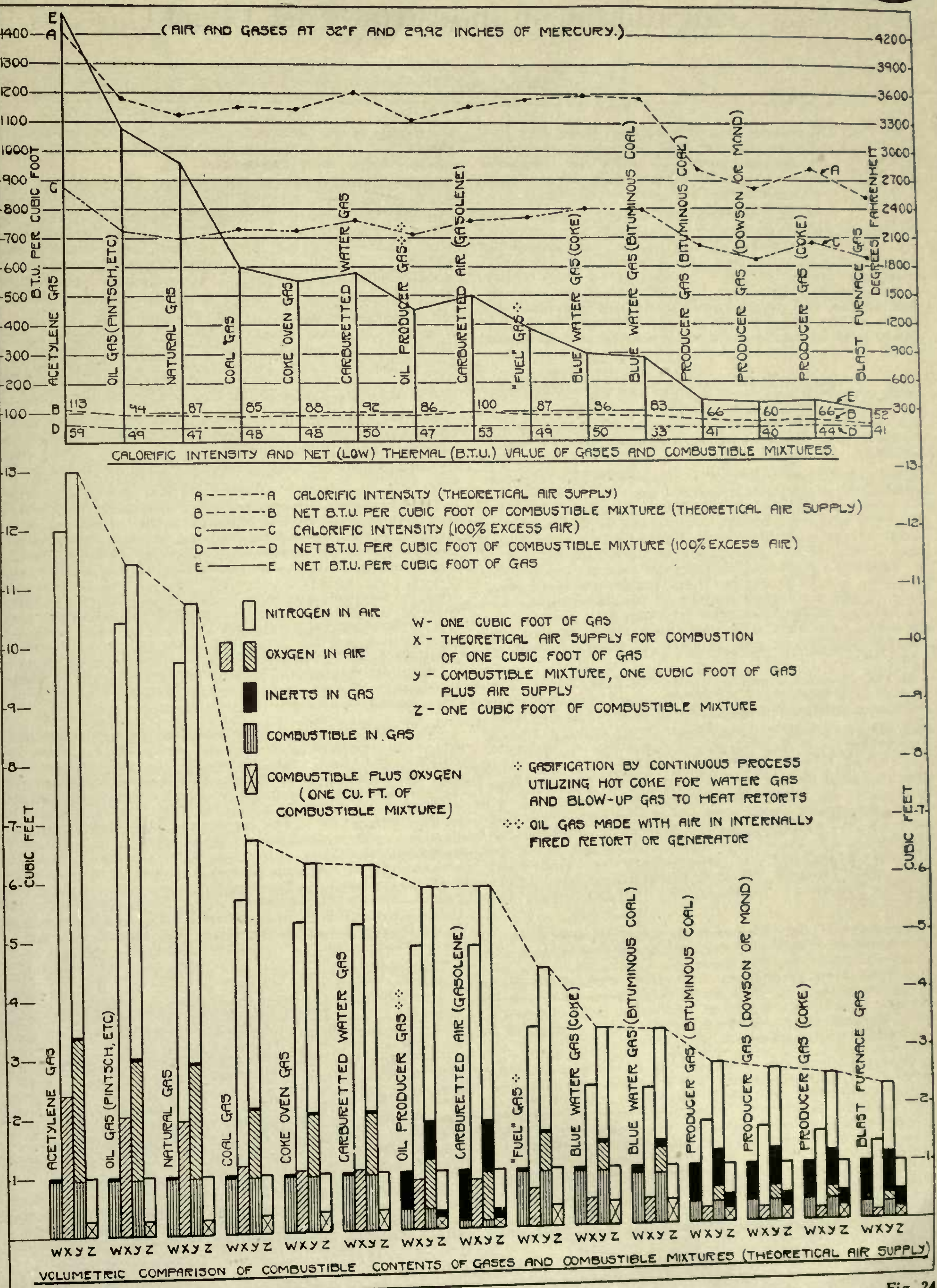


Fig. 24

Composition of Industrial Fuel Gases

THE composition of industrial gases, their combustible mixtures, and products of combustion, are essential factors governing the selection of gases and suitable equipment for the production and application of heat, power or light.

When a gas is to be used as a reducing agent or for some special purpose not requiring combustion, the composition of the gas itself is generally all that need be considered. When employed as a source of heat energy, however, it is necessary to consider many other factors outlined by the chart on page 33, with particular reference to **the influence of the composition of the gas or its combustible mixture upon the nature of the operation** to be conducted and the design of apparatus to be employed for the generation and application of heat.

When the material difference in B. t. u. value of the common industrial gases is considered together with the comparatively slight difference in heating value of their combustible mixtures, it is apparent that **chemical composition is of greater importance than B. t. u.** value in determining their field of usefulness.

The quantity of inerts or incombustibles is relatively small in the majority of industrial gases, with the exception of producer gas, of which over 60% is inert matter. The inert content is important insofar as it relates to the increase in volume of gas or combustible mixture necessary to furnish a given amount of heat energy, and to the nature and cost of equipment and operations necessary for manufacture and distribution; but it is apparent from comparison of the inert content of the combustible mixtures of the different gases that **the heating value of the gases is determined more by the elements forming the combustibles than by the percentage of inerts in the gases or in their combustible mixtures.**

In the generation and utilization of heat, we are concerned more with the heating value and composition of the combustible mixture than with that of the gas itself, although the composition of the gas enters into the problem of distribution, as is illustrated by the action of carbureted water gas, oil gas and natural gas in cold weather.

The relative importance of chemical composition, with reference to both the character of the heat released and the chemical influence of the products of combustion upon the product to be heated or heating apparatus, is not generally appreciated. **The striking changes resulting from the mixture of gas and the air necessary for combustion, the further changes following ignition and combustion, and the influence of excess air,** are illustrated by the chart on page 39.

Consideration of the comparatively large volume of products of combustion of each gas, which are heated to the maximum temperature of the heating process, will indicate **the economies attainable through efficient utilization of the spent gases** to perform useful work. The heat in these gases may be utilized to preheat the air or fuel prior to combustion, or, as is generally more desirable, to preheat the material before it is exposed to the final working temperature.

The spent gases may be considered as a vehicle for conveying heat in the manner that a wire is employed in conveying electricity. So-called **quiescent atmospheres do not actually exist.** The advantages that result from the transfer of heat by convection, and the natural motion of hot gases created by a temperature differential, regardless of the source or manner of heat generation, indicate the possibility of utilizing an apparent disadvantage in composition not only for effecting economy in fuel but for improvement in methods of heat application.

The efficiency of such utilization is dependent upon the design of the furnace or other appliance, and particularly the method of heat application and manner of handling the material and exposing it to the heat.

The field of usefulness of any gas is not entirely dependent upon the B. t. u. value or composition of the combustible mixture or products of combustion. The design of equipment and method of releasing heat exert no small influence upon the operating result, and necessitate consideration of the physical conditions governing the design of mixers, combustion chambers, rate of energy input, temperature, time and other factors which are not apparent in the gas itself.

The comparatively high calorific intensity of water gas makes it unsuited to certain forms of equipment, such as gas engines, which may be employed to advantage with others, such as natural gas, city gas or producer gas. This relation may be reversed in other operations requiring the use of blow torches or special heating equipment for high temperature operations.

The composition of the products of combustion must be considered in relation to its influence upon the product, because furnace atmosphere plays an important part in some processes which may require either reducing, neutral or oxidizing conditions.

The apparent advantages of a comparatively cheap fuel may be offset by the chemical action of the resultant gases upon the process or apparatus, which would necessitate modifications in the furnace design or process in order to retain the advantage that may be represented by the form or price of such fuel. This is illustrated by the practice of employing crucibles for melting certain metals to decrease the possible effect of oxidation, of packing material in sealed boxes or pots, and by the muffle type of furnace employed for vitreous enameling; in each case permitting the application of heat without contact between the material to be heated and the products of combustion. Special atmospheres may be secured in muffles by passing suitable gases into the muffle, which may or may not be sealed.

Such limitation is not confined to fuels alone, as it is frequently encountered in the arc or resistance methods of releasing heat from electricity due to the gasification of the electrodes or resistance material. In most cases it is desirable to maintain neutral or reducing atmosphere in the heating zone to protect the material from oxidation. While this may be readily accomplished with most fuels in properly designed furnaces by control of the air supplied for combustion, it is comparatively difficult with others. Such a neutral or reducing atmosphere may be readily secured in electric furnaces releasing heat through some form of carbonaceous resistance material, while a different form of resistance material may necessitate the use of a material such as oil to provide the proper atmosphere in the heating zone, even though the heat itself is generated by an electrical process.

The gases, such as coal gas, carbureted water gas, etc., commonly known as "city gas" of about 600 B. t. u., have a lower flame temperature than unmixed blue water gas of about 300 B. t. u., although the B. t. u. values of the combustible mixtures are approximately the same. The difference in chemical composition of the gases themselves, resulting in a comparatively insignificant difference in odor, which is frequently desirable in order to detect leaks, makes the so-called "city gas" generally preferable for distribution to domestic consumers. Likewise, **the difference in chemical composition of the combustible mixture or the products of combustion frequently determines the field of usefulness in heat, power or illumination, regardless of price on a heat-unit basis.**

The fundamental significance of chemical composition, as affecting the quality and cost of product, must be considered in the selection of gases and of equipment for the transformation and application of their energy values.

COMPARISON OF INDUSTRIAL GASES

VOLUMETRIC COMPOSITION OF GAS, COMBUSTIBLE MIXTURE AND PRODUCTS OF COMBUSTION

D-21
2920

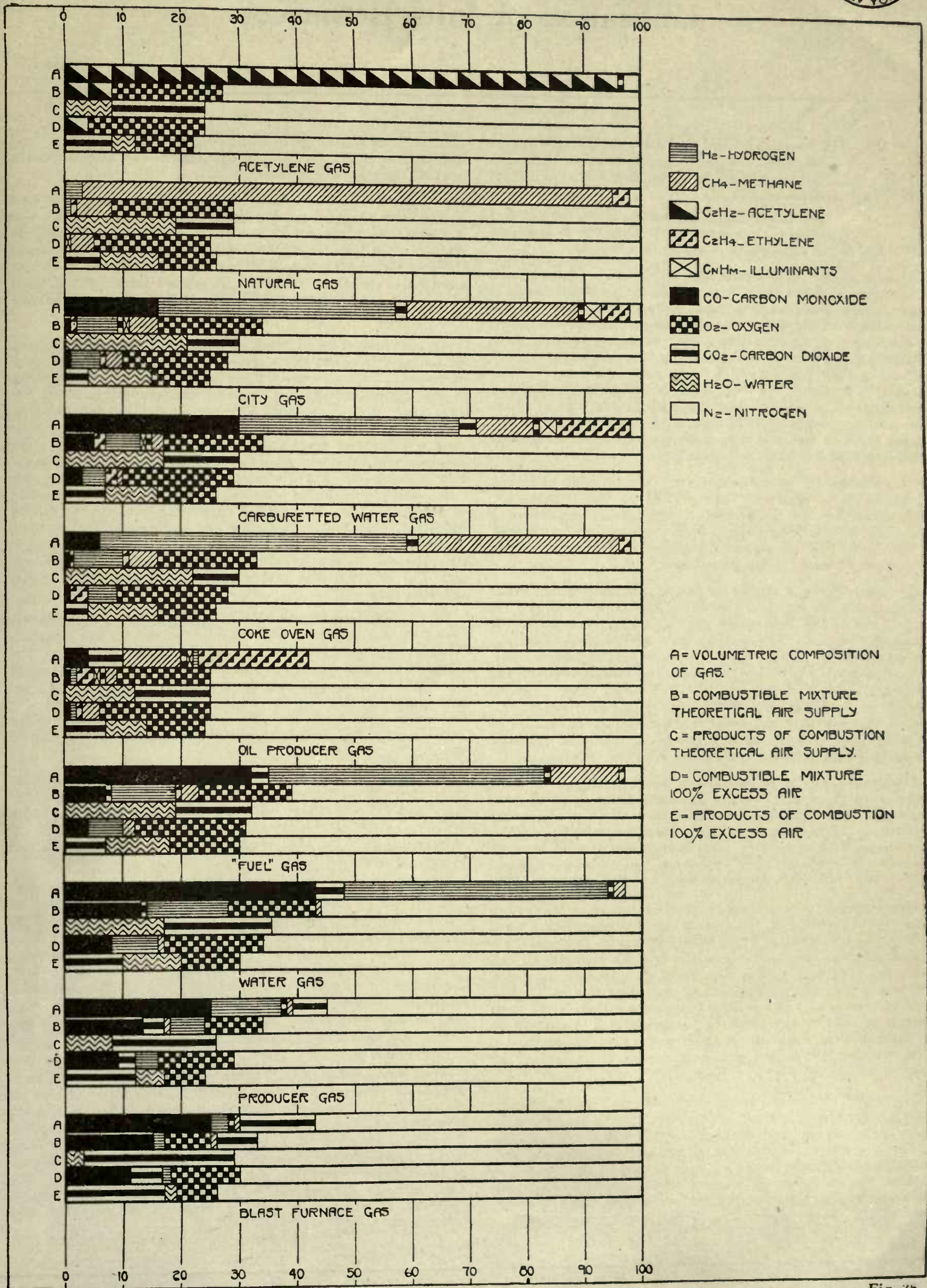


Fig. 25

Utilization of Fuel Resources

THE so-called "fuel problem" is but one factor in the real problem, i. e., the efficient utilization of all the energy and commodity values in natural fuel resources.

As regards the energy values alone, the problem involves the production, transportation and utilization of fuel in the application of heat, power or light.

A field of usefulness exists for each form of fuel used in suitable apparatus. The scope of the respective fields is not measured solely by price and thermal value, but includes that intangible value due to the physical or chemical association of the fuels and the mechanical form of the apparatus. This element may be defined as **"form value,"** in contrast to thermal value as commonly expressed in "heat units" (B. t. u.) or "heat balance." **A survey of the field is incomplete without consideration of all the factors that govern the production and transportation of fuel, and the selection of the proper form of fuel and proper equipment for the efficient application of heat to useful work.**

"A solution of the fuel problem" is frequently advanced by advocates of some one form of fuel, or those urging the proposition that the utilization of fuel for the generation of electricity, or production of gas in super-transforming stations, is the logical method of conserving fuel resources in meeting the modern demand for energy service.

However, the requirements for power, illumination, industrial and domestic heating, and the chemically important need for by-products are so interwoven that all these needs cannot be separately treated. **The energy and commodity requirements must be appraised in their interdependence, and determination made of the most practical means for meeting these requirements.** Economies that may be effected in production and transportation of fuel must be considered together with the possible economies in utilization of different forms of solid, liquid and gaseous fuels and electrical energy **in more efficient appliances adapted to each.**

The possibility of improving present methods must be borne in mind, as well as the advantages likely to result from the substitution of **better methods adapted to present-day conditions.** The quantity of fuel required to meet the country-wide demand has grown to such a stupendous total that its provision in the customary forms is becoming increasingly difficult and results in tremendous wastes of material and effort.

The waste in production of oil is far greater in proportion than that of coal, but **the waste in transportation and utilization** is proportionately greater with coal. **The handling of coal engages over one-third the freight capacity of the country,** while the more flexible form of oil favors its simple and cheap distribution through an extensive system of pipe lines thousands of miles in length. **Conversion of the heat energy in coal to the form of gas simplifies the problem of distribution and utilization,** particularly in congested areas, which condition warrants consideration of **"form value"** in distribution as well as in utilization.

The traffic congestion at the terminals and on the streets, from the distribution of coal and removal of ash, and the enormous losses and property damage due to smoke, soot and ash, as also the loss by destruction of valuable by-products, etc., following the transportation and use of coal in the customary manner and form, are in marked contrast to the conditions made possible by substitution of the more mobile forms of energy such as oil, gas or electricity. These contrasting conditions illustrate **the influence of the "form value" of energy and appliances upon the cost of transportation and ultimate cost at the point of consumption.**

In 1915, before the price of coal was advanced by war conditions, the average cost of bituminous coal at the mines was less than $1.25 per ton. The difference between this figure and the price paid by the consumer represented the charges of the carriers and dealers, from which it is apparent that any **economies possible through improved methods of production would have exerted very little, if any, influence in reducing the price to the consumer.**

As an illustration of what can be gained by transforming its energy into other forms, in addition to the saving in transportation: The same coal utilized in the by-product coke oven, or the central station gas plant by the coal-gas process, has been made to yield domestic coke, gas for heating and illumination, and by-products valued at about $15. If its energy values were entirely converted into a gas suitable for the average domestic and industrial heating requirements or for the generation of power, the yield in gas and by-products would be over $25. **Additional gains resulting from the transportation of energy in the form of gas through pipes, or electricity by wires,** are obvious, including the diversion of coal-carrying equipment to more essential and profitable uses; the saving in fuel incident to better methods of heat application possible with gas or electricity, and a general improvement in living conditions.

The losses and likewise the opportunities for improvement in the utilization of fuel are shown by the diagrams on page 41, representative of current practice. When the additional **losses in the production and transportation of fuel** before its combustion are considered together with the still greater **losses in the application of heat, power or light** after transformation, the condition is still more striking and suggests the desirability of improvement in methods of utilizing the energy resources.

An extension of the electrical program is desirable to meet the need for power and illumination, but the limitations of price and **"form value"** in the arc, resistance and induction methods of releasing heat, and the special nature of electrical equipment, limit the field of electricity as a substitute for fuel in heating operations.

Reconstruction of the "city gas" industry offers an attractive field for development because of the opportunity for better utilization of the heat energy in bituminous coal and the economic progress that will follow an extended use of cheaper gas. **Better methods of gasification and distribution, elimination of the problems incident to the use of oil, anthracite coal and "domestic coke," and utilization in improved appliances,** such as furnaces, gas engines, etc., **should result in better and cheaper methods of utilizing fuel resources,** with advantage to the community as well as the gas industry.

That one coal pile and transforming station may be a source of by-products and energy in the form of gas or electricity for domestic and industrial heating is not an idle dream. Every essential step has been proved in practice. Public opinion needs to be awakened to **the advantages that will follow further extended use of the more mobile forms of heat energy, such as gas or electricity,** and to the fact that those advantages can be gained, however, only through far-reaching changes in present methods of provision and utilization.

HEAT DISTRIBUTION IN ENERGY CONVERSION PROCESSES

ECONOMIC VALUE OF BY-PRODUCTS, POSSIBLE HEAT RECOVERY AND THE EFFECT OF OPERATING CONDITIONS NOT CONSIDERED

D-24
2521

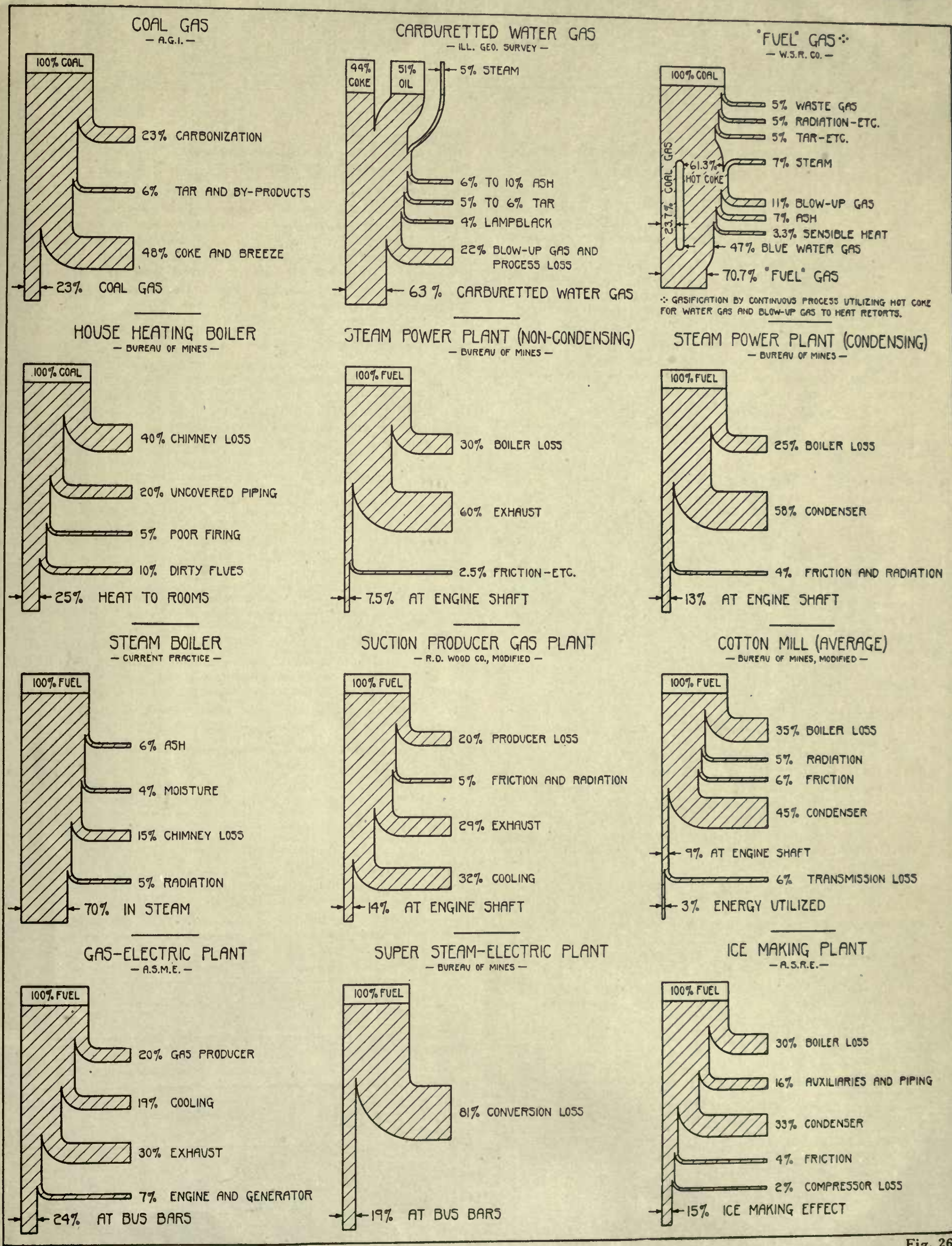


Fig. 26

DATA ON SPECIFIC HEATS AND MELTING POINTS

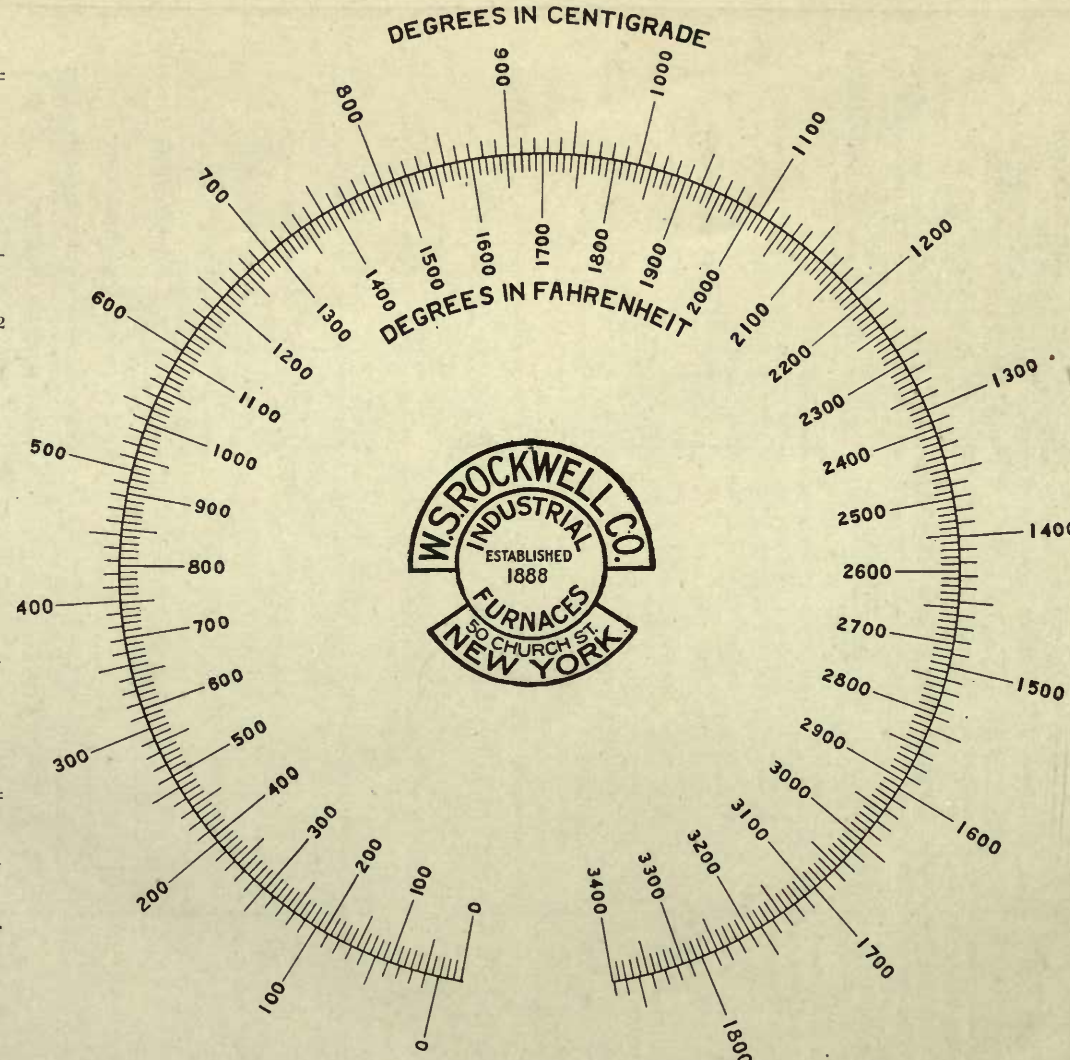
	Melting Point Deg. F.	Average Specific Heat	Latent Heat of Fusion B.t.u. per lb.	Specific Gravity	Pounds per cu. ft.
Aluminum	1217	0.238	138.2	2.70	168
Antimony	1166	0.0513	72.5	6.69	417
Brass	1500 / 1950	0.091	....	....	511–542
Copper	1981	0.1008	77.9	8.89	554
Gold	1945	0.0317	29.34	19.30	1204
Iron, Gray cast	2050 / 2300	0.11 / 0.22	41.7	7.13	445
Lead, Solid	621	0.0359	10.6	11.35	708
Lead, Fluid	....	0.04	....	10.65	665
Manganese	2300	0.119	....	7.42	463
Molybdenum	4532	0.095	....	9.01	562
Nickel	2646	0.11	8.37	8.70	543
Platinum	3190	0.0369	48.9	21.37	1334
Rhodium	3560	0.058	....	12.44	776
Silver	1762	0.060	45.8	10.60	661
Tin, Solid	450	0.056	25.2	7.30	455
Tin, Fluid	....	0.0702	....	6.98	436
Titanium	3263	0.1125	....	4.50	281
Tungsten	6152	0.0333	....	18.60	1161
Vanadium	3128	....	....	5.69	355
Water (39° F.)	32	1.00	144.0	1.00	62.43
Zinc	786	0.0998	49.6	7.19	449

CONVERSION TABLE OF EQUIVALENTS

A—Quantities of Heat
B—Rate of Doing Work

	A: Kilo-watt Hour / B: Kilo-watt	A: B. t. u. / B: B. t. u. per Hour	A: Calorie* / B: Calo-ries* per Hour	A: Horse Power Hour / B: Horse Power	A: Lb. Water 1° F. / B: Lb. Water 1° F. per Hour
A Kilo-watt hour / B Kilo-watt	1	3411	860.3	1.341	3411
A B.t.u. / B B.t.u. per hour	0.00029	1	0.252	0.000393	1.0000
A Calorie / B Calorie per hour	0.001162	3.968	1	0.00156	3.968
A Horse Power hour / B Horse Power	0.7457	2544	641.7	1.	2544
A Lb. Water 1° F. / B Lb. Water 1° F. per hour	.000293	1	0.252	0.000393	1

*Large calorie (kilogram degree centigrade).
The numbers in table give the value of the unit at left in terms of the unit named at the top of the column.



$$\text{Degrees Fahrenheit} = 1.8\ (\text{Degrees Centigrade} + 40) - 40$$

$$\text{Degrees Centigrade} = \frac{\text{Degrees Fahrenheit} + 40}{1.8} - 40$$

CONVERSION TABLE OF CONSTANTS OF HEAT TRANSMISSION AND CONDUCTION

*Calories per sq. cm.	= 3.687 B. t. u. per sq. ft.
B. t. u. per sq. ft.	= 0.2712 calories per sq. cm.
Calories per sq. cm. per cm. thick	= 1.451 B. t. u. per sq. ft. per in. thick
B. t. u. per sq. ft. per in. thick	= 0.6892 calories per sq. cm. per cm. thick
Calories per sec. per sq. cm. per 1°C per cm. thick	= 2903 B. t. u. per hour per sq. ft. per 1°F per in. thick
B. t. u. per hour per sq. ft. per 1°F per in. thick	= 0.0003445 calories per hour per sq. cm. per 1°C per cm. thick

**Gram (small) calorie used in above table = 0.001 Kilogram (large) Calorie = 0.003968 B. t. u.*

HEAT EQUIVALENTS

Unit	Equivalent Value in Other Units
1 British thermal unit =	1055 watt seconds. 778.3 ft. lbs. 107.6 kilogram meters. 0.0002931 kw. hour. 0.00039305 h. p. hour. 0.0000685 lb. carbon oxidized. 0.001030 lb. water evap. from and at 212° F.
1 kw. hour =	1000 watt hours. 1.341 h. p. hours. 2,655,000 ft. lbs. 3,600,000 joules. 3411 B. t. u. 367,100 kilogram meters. 0.234 lb. carbon oxidized. 3.52 lbs. water evap. from and at 212° F. 22.77 lbs. water raised from 62° to 212° F.
1 h. p. hour =	0.7457 kw. hour. 1,980,000 ft. lbs. 2544 B. t. u. 273,745 kilogram meters. 0.174 lb. carbon oxidized. 2.62 lbs. water evap. from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.
1 lb. carbon oxidized =	14,600 heat units. 1.11 lbs. anthracite coal oxidized. 2.5 lbs. dry wood oxidized. 24.3 cu. ft. illuminating gas. 4.28 kw. hours. 5.739 h. p. hours. 11,363,180 ft. lbs. 15.04 lbs. water evap. from and at 212° F.
1 lb. water evaporated = from and at 212° F.	0.2841 kw. hour. 0.3811 h. p. hour. 970.4 B. t. u. 104,415 kilogram meters. 1,022,772 joules. 755,262 ft. lbs. 0.066466 lbs. carbon oxidized.

Calorie = 3.968 B. t. u.
B. t. u. = 0.252 calorie.
B. t. u. per pound = 0.55556 calorie per kilogram.
Calorie per kilogram = 1.8 B. t.u. per pound.
Calorie per liter = 112.37 B. t. u. per cubic foot.
B. t.u. per cubic foot = 0.0089 calorie per liter.
Calorie per cubic meter = 0.11237 B. t. u. per cubic foot.
B. t. u. per cubic foot = 8.899 calorie per cubic meter.

QUALITY and cost of heat-treated products are greatly influenced by type, layout and operation of heating and handling equipment and form of heat energy employed.

We make a specialty of designing and constructing modern industrial heating equipment, adapted to fuel or electricity, for the metallurgical, chemical, ceramic and other industries.

Our practical experience of over thirty years is illustrated by the following list of furnaces, practically **all of which we have built in a variety of types and sizes to suit individual requirements.**

ANNEALING FURNACES. **Rolling mill type.** Improved underfired downdraft design with perforated floor to permit delivery of heat to bottom and top of charge, with or without recuperation; improved side-fired design for comparatively low charges.

Single or multi chambers; single or double end; all sizes for ferrous and non-ferrous metals in form of ingots, bars, rods, sheets, coils, wire, tubes, etc.; miscellaneous stamped or drawn parts, such as cups, shells, etc.; light forgings, castings, etc.

Automatic conveyor, revolving (with or without retort), rotary table and "beam" types for ferrous and non-ferrous pieces of uniform size in large quantities, with provision for automatic charging, preheating, heating, discharging, quenching, draining and delivery, as required.

Semi-automatic pan and pusher types for irregular shapes carried on pans or trays, or regular shapes moved on rails.

Bright annealing for non-ferrous metals; **continuous conveyor type** with water seals; **pot type** for fine wire, etc.

Car type with removable hearth for heavy and irregularly shaped castings, forgings, etc.

Car-and-ball type for annealing wire, sheets, etc., in packing boxes; heat-treatment of large forgings, castings, etc.

Removable roof type for steel castings, heavy forgings, etc.

Side-opening type with movable partitions to accommodate relatively small parts or shafts over 100 ft. long.

Stationary type with single or multi chambers, with or without charging machines or packing boxes.

Stoker-fired type for miscellaneous heavy work.

Direct recuperative type for recovery of heat in spent gases or in outgoing hot charges to preheat incoming charge; continuous or intermittent heating and handling.

BAKING FURNACES. For drying wire, miscellaneous metal pieces, heat-treating chemical products, etc.

BILLET HEATING FURNACES. **Continuous and intermittent types** for ferrous and non-ferrous ingots, billets, cakes, etc., for rolling or forming; heat-treatment of uniformly shaped pieces, such as car axles, etc.; single or multi-chamber design, with different arrangements of working openings.

BLAST GATES. **Improved air-tight blast gate** for air, etc.; **special types** for liquids, powders, etc.

BLOWERS. **Turbo, positive pressure and fan types** for air, with belt or direct motor drive; **argand or turbo types** for steam.

BLUING FURNACES. **Continuous and stationary types,** with or without muffles, for bluing large quantities of wire, etc.; **automatic type** for miscellaneous small parts.

BRAZING FURNACES. For tubes, wire, etc.

BURNERS. Oil or gas—**10 types** in a variety of sizes—for high pressure steam and high or low pressure air; **combination types; special types** for mechanical atomization of oil.

CARBONIZING FURNACES. **Single and multi-chamber types,** with or without recuperation, in a variety of sizes with different arrangements of chambers and working openings; **special types** for carbonizing in retorts with gas.

CORE OVENS. **Special designs** in large sizes with movable reels, cars or conveyors.

CYANIDE FURNACES. **Single and twin-pot types,** with or without preheating chambers.

DRYING FURNACES. **Rotary, conveyor and stationary types** for continuous and intermittent operations, with or without muffles, for metal goods, chemical products, etc.

ELECTRIC FURNACES. **Resistance type** in automatic, semi-automatic and stationary designs for miscellaneous heat-treatment operations on metallurgical, chemical, ceramic and other products requiring accurate control of chamber atmosphere and temperature.

ENAMEL FURNACES. For burning and melting; **standard muffle type** for coal, oil or gas; **semi-muffle type** for intermittent heating with oil or gas and automatic control of fire; **improved downdraft recuperative type,** with muffle, for bituminous coal, oil or gas; **reverberatory type** for melting; **electric resistance type** for burning—continuous or intermittent operation.

FORGE FURNACES. **Economizer shield type** to protect operator and utilize heat from working opening to preheat air for combustion.

Single or double end, for short or long heats, working off the bar or with cut stock for serving drop hammers, upsetting machines, rivet, bolt and nut machines, etc. Double end for long rod heating, to serve continuous rivet and bolt making machines.

Slot and magazine types for bolt heading.

Miscellaneous portable types for short end heats, tool dressing, etc.

Blacksmith type for general work.

Bulldozer type for small hammer work.

Heavy forge type, single or multi doors, for large steam hammers, presses, etc.

Recuperative type for preheating fuel or air, or for direct recovery in preheating charge.

GALVANIZING FURNACES. **Continuous and intermittent types** for wire, sheets, tubes, etc.

GLASS FURNACES. For melting and annealing glass.

HARDENING FURNACES. **Automatic, semi-automatic and stationary types** in a variety of sizes with different methods of heating and handling material; **pot type** for hardening in baths.

HEATING FURNACES. **Continuous, semi-automatic and stationary types** for miscellaneous forming operations.

HEAT-TREATING FURNACES. **Automatic, semi-automatic and stationary types,** with direct or indirect heat recovery; size and arrangement of chambers and working openings, methods of heating and handling, etc., adapted to individual requirements, using coal, oil, gas or electricity; **semi-muffle and muffle types; combination types** for continuous annealing, normalizing, hardening, tempering, etc.

INCINERATING FURNACES. **Special types** for disposal of waste products.

JAPANNING FURNACES. **Continuous and stationary types** in large sizes for special drying or baking operations.

KILNS. **Special designs** for ceramic products.

MELTING FURNACES. **Stationary and tilting crucible and reverberatory types** for non-ferrous metals, enamel powder and special purposes.

MUFFLE FURNACES. For annealing, enameling, scaling, rust-proofing, assaying and miscellaneous purposes.

OIL APPLIANCES. Burners; oil pumps; relief valves; heaters; unloading hose; storage tanks; burner plates; blowers; blast gates; special combustion chamber tiles; etc.

PATENTING FURNACES. For continuous heat-treatment of wire.

PLATE HEATING FURNACES. For miscellaneous forming operations in ship, railroad and boiler shop work; **angle heating type** for angles, beams, rods, etc.

Continuous type for large quantities of uniformly shaped pieces for hot press work.

POT FURNACES. **Single and multi-pot types,** with or without preheating chambers, for heat-treatment operations in baths of oil, lead, salts, etc.; melting soft metals, etc., with or without spout and valve or special means of discharging or handling material; **special types** for bright annealing, carbonizing and miscellaneous processes.

REGENERATIVE AND RECUPERATIVE FURNACES. For high temperature operations, such as forging, welding, melting, etc., utilizing heat in spent gases to preheat air and fuel.

Direct recovery type, in continuous and stationary forms, with single or multi chambers, utilizing heat in spent gases or hot charge to preheat incoming material.

RE-HEATING FURNACES **Intermittent and continuous types,** with single or multi chambers or doors.

RETORT FURNACES, in different types and sizes, with metal or refractory muffles.

REVERBERATORY FURNACES. For melting, heavy forging, etc.

RIVET FORGES. **Portable and stationary types.**

ROASTING FURNACES. **Special types** for roasting ores, chemical products, etc.

ROD HEATING FURNACES. **Single and double-end types** for short or long heats.

SCALING FURNACES, with or without muffles, for ferrous and non-ferrous metal products.

SHEET AND PAIR FURNACES. **Continuous and stationary types.**

SINGEING FURNACES. For singeing cloth, carpet, etc., with hot plates or gas flames.

SPRING FITTING FURNACES. **Automatic, semi-automatic and stationary types; combination fitting, hardening and drawing stationary type** for vehicular springs; **continuous and stationary types** for one, two or four fitters on car springs, etc.

STOKER-FIRED FURNACES. With or without recuperation, for miscellaneous heating operations.

TEMPERING FURNACES. **Automatic, semi-automatic and stationary types** in a variety of designs and sizes; **special types** with stationary or movable dies for saws, etc.; **miscellaneous designs** for delicate parts, such as needles, etc.

TINNING FURNACES. **Continuous type** for wire, sheets, etc.; **special types** for long tubes and miscellaneous small stamped and cast parts.

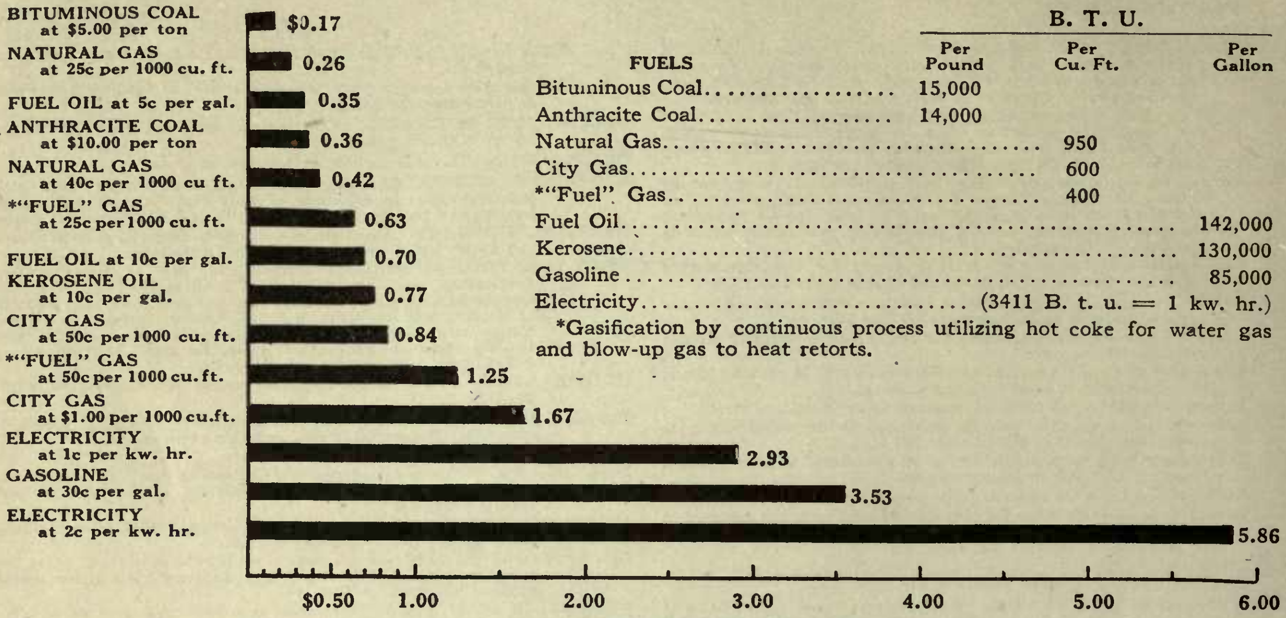
TIRE HEATING FURNACES. **Stationary and continuous types** for shrinking operations.

VARNISH BOILING FURNACES. For varnish, oils, gums, greases, etc.

SPECIAL DESIGNS OF FURNACES
for
Metallurgical, Chemical, Ceramic and Other Processes

INDUSTRIAL FUELS

Comparative Cost Per Million B. T. U. at Unit Prices



Assumed Thermal Value

FUELS	B. T. U. Per Pound	B. T. U. Per Cu. Ft.	B. T. U. Per Gallon
Bituminous Coal	15,000		
Anthracite Coal	14,000		
Natural Gas		950	
City Gas		600	
*"Fuel" Gas		400	
Fuel Oil			142,000
Kerosene			130,000
Gasoline			85,000
Electricity	(3411 B. t. u. = 1 kw. hr.)		

*Gasification by continuous process utilizing hot coke for water gas and blow-up gas to heat retorts.

Fig. 28

> ***Quality and cost of finished product****—not cost of fuel, cost of labor, mere tonnage, nor indication of uniform chamber temperature—* ***are the determinative tests of industrial heating operations.***

"FURNACE AND FUEL TO SUIT CONDITIONS"—

is our rule governing consideration of new or improvement of existing industrial heating equipment to suit **your** needs under **your** plant conditions.

We make inspection of plant, devise methods of heating and handling material, furnish complete industrial heating equipment adapted to **your** particular plant conditions, and guarantee results, using **coal, oil, gas or electricity,** as **your** best interests require.

W. S. ROCKWELL COMPANY

Furnace Engineers and Contractors

50 CHURCH STREET NEW YORK
(Hudson Terminal Bldg.)

Works: NEWARK, N. J.

Branches: Chicago — Ellsworth Bldg.; Cleveland — Engineers' Bldg.; Detroit — Majestic Bldg.

British Representative: GIBBONS BROS., *Ltd.,* Dudley, Worc., England